The Salton Sea

Geology, History, Potential Problems, Politics, and Possible Futures of an Unnatural Desert Salt Lake

Larry C. Oglesby

Department of Biology, Pomona College, Claremont, California 91711

MEMOIRS OF THE
SOUTHERN CALIFORNIA ACADEMY OF SCIENCES
VOLUME 10
October 18, 2005

MEMOIRS OF THE SOUTHERN CALIFORNIA ACADEMY OF SCIENCES

The MEMOIRS of the Southern California Academy of Sciences is a series begun in 1938 and published on an irregular basis thereafter. It is intended that each article will continue to be of a monographic nature, and each will constitute a full volume in itself.

Contributions to the MEMOIRS may be in any of the fields of science, by any member of the Academy. Acceptance of papers will be determined by the amount and character of new information and the form in which it is presented. Articles must not duplicate, in any substantial way, material that is published elsewhere. Manuscripts must conform to MEMOIRS style of volume 4 or later, and may be examined for scientific content by members of the Publications Committee other than the Editor or be sent to other competent critics for review.

Because of the irregular nature of the series, authors are urged to contact the Editor before submitting their manuscript.

Copies of this memoir may be obtained for $15.00 from the address below.

Daniel A. Guthrie, Editor
℅ W.M. Keck Science Center
925 N. Mills Ave.
Claremont, Ca. 91711
dguthrie@jsd.claremont.edu

THE SALTON SEA

Geology, History, Potential Problems, Politics, and Possible Futures of an Unnatural Desert Salt Lake

Larry C. Oglesby

Department of Biology, Pomona College, Claremont, California 91711

MEMOIRS OF THE
SOUTHERN CALIFORNIA ACADEMY OF SCIENCES
VOLUME 10
October 18, 2005

CONTENTS

Figures

PREFACE

To Larry Oglesby, the Salton Sea was one of the most interesting places on earth. He first became acquainted with it as a graduate student at Berkeley in the 1960s. Later, as a faculty member at Pomona College in Claremont, California, he used it in his research on salt and water balance in several invertebrates including pileworms and snails. He was the advisor of many senior theses on facets of the biology of the Salton Sea during his thirty years at Pomona College. In addition, he made it an important part of his field class in Aquatic Biology, with a three day field trip there every year during which he and his students measured many parameters of the Sea. Some of the data in the manuscript are from those field trips. Though his main focus was the invertebrates, he became fascinated with every aspect of the sea—its history, geology, and biology.

After his early retirement in 1998 due to health problems, he spent his time writing a manuscript which would encompass all his interests in the Sea. He was very concerned about what was happening at the Sea, and incorporated some thoughts about that too. At the time of his death, in April 2001, he had finished the manuscript except for some editing.

These are Larry Oglesby's thoughts on the Salton Sea from the vantage point of one who followed it closely for thirty years. With the rapid changes to the Sea now being proposed, it is a record of the Salton Sea in what may have been its most productive years.

Alice Oglesby
Claremont, California
March 31, 2005

EDITOR'S NOTE

A short time after Larry was diagnosed with cancer and retired from college teaching, I approached him about participating in a symposium on the Salton Sea for the Southern California Academy of Sciences. Larry agreed to prepare a paper on the invertebrates, his specialty, but the project grew, eventually incorporating all his lifetime work on the sea and covering not only invertebrates but all aspects of the Sea's history and wildlife.

Larry was a consummate scientist and his manuscript includes much characteristic scientific shorthand. He insisted on using the metric system for measurements and using d for day, yr for year, etc. He used a notation for salinity concentration that may not be familiar to those not working in limnology. Rather than g/L (grams per liter), Larry uses g l^{-1}. The Bibliography contains all the works consulted by Larry, not just referenced works and is probably the most complete bibliography of material on the Salton Sea.

After Larry's death it was felt that this manuscript, if published, would be a fitting memorial to his work and to his knowledge of the Salton Sea, and provide a valuable history of the biology, geology, and other aspects of the Sea up to the year of his death (2001). The Southern California Academy of Sciences, of which Larry was a long-time member, agreed to undertake this publication as a memoir with the generous financial support of the Oglesby family. I have done little to Larry's original manuscript other than some minor editorial corrections. Alice Oglesby has done most of the final preparation as a lasting tribute to her husband.

Daniel A. Guthrie, Editor
Southern California Academy of Sciences

ACKNOWLEDGMENTS

It is a great pleasure to thank the many students in 30 years of Pomona College Aquatic Biology classes for their help in making detailed observations, collecting data, and constant good cheer. Their field notes and project reports have been a gold mine of valuable information. I am pleased to thank my research assistants and senior thesis students for their excellent work both in the field and in the laboratory: Charles Anderson, Tanya Bauriedel, John Bishop, Abigail Breuer, Michael Carroll, Douglas Christ, Nicole Dobroski, Margaret "Peggy" Fastnow, William Hargreaves, Wayne "Chip" Hogue, Dierdre Kuhl, Mira Liao, Jan Low, Erick Robinson, Lena Shiroma, and Susan Summit, all from Pomona College, Heather Duncan of Swarthmore College, and Judy Swift of Colby College.

I have greatly benefited from discussions with James T. Carlton (Director, Williams College-Mystic Seaport Program), Ed Collins (Imperial Irrigation District), Clifton Coney (Malacology Collections Manager, Los Angeles County Museum of Natural History), Barry Costa-Pierce (Director, Mississippi-Alabama Sea Grant Consortium), William Davis (biology, University of California, Irvine), Deborah Dexter (biology, San Diego State University), Brian Ebersole (Science Librarian, Pomona College), Craig Engel (former Manager, Salton Sea State Recreation Area), John Fitch (former Research Director, California Department of Fish and Game), Taber Hand (natural resources, University of Maryland), Ari Hershowitz (Natural Resources Defense Council), Norman Hogg (biology, California State Polytechnic University, Pomona), Gary Hurd (Orange County Natural History Museum), Stuart Hurlbert (biology, San Diego State University), Robert R. Ireland (University of California Lawrence Livermore National Laboratory), Richard C. Johnson (Salton Sea State Recreation Area), the late Charlotte Mangum (biology, College of William and Mary), William A. Newman (Scripps Institute of Oceanography), Alice S. Oglesby (microbiology, Western University of Health Sciences), David D. Oglesby (geology, University of California, Riverside). Wayne Parker (Manager, former State Warmwater Fish Hatchery), Donald J. Reish (biology, California State University, Long Beach), Paul Remeika (Park Paleontologist, Anza-Borrego Desert State Park), Ginger Ridgeway (Curator, Agua Caliente Cultural Museum), Jerry Schaefer (ASM Affiliates), J. M. "Tex" Ritter (former Manager, Salton Sea State Recreation Area), Michael Rymer (US Geological Survey), Alan Schoenherr (biology, Fullerton College), James G. Setmire (US Geological Survey), the late Ralph I. Smith (zoology, University of California, Berkeley), Dwight Taylor (California Academy of Sciences), Howard Wilshire (US Geological Survey), William O. Wirtz II (biology, Pomona College), Jay von Werlhof (Director, Imperial Valley College Desert Museum), Fred Worthley, Jr. (Region 5 Manager, California Department of Fish and Game), Jonathan Wright (biology, Pomona College), and Donald Zenger (geology, Pomona College). D. Reynolds and S. Householder of Inland Paper Board and Packaging provided frank and informative discussions of an incident of illegal dumping. All will be happy to know that I accept full responsibility for any errors that remain.

A number of research students and my sons Ian and David accompanied me on collecting trips, enduring winter cold and horrible summer heat and horseflies, being rewarded only with worms, snails, and date milkshakes. David Dwiers, machinist at Pomona College, and his son Daniel accompanied me on many class field trips, helping greatly in many ways. Especial thanks go to the late Gerhard Ott, biology technician extraordinaire at Pomona College, whose help and friend-

ship on class and other field trips were so very much appreciated. Thanks to Gerhard for several rescues from desert mishaps! I have greatly enjoyed many conversations with fishers, campers, residents, and snowbirds at the Salton Sea. Particular thanks go to the personnel of the Salton Sea State Recreation Area for granting us access to collecting sites and for many informative discussions, and of the Sonny Bono Salton Sea National Wildlife Refuge for discussions about bird distributions and issues. Thanks to Jean Beckner, librarian at Honnold Library Special Collections for her help in finding pertinent literature.

This research was supported by grants from the National Science Foundation, the US Department of Energy, the GTE Foundation, the Howard Hughes Medical Institute, and Pomona College.

Larry C. Oglesby
April 17, 2001

In addition to the people noted above, I want to give special thanks to Dan Guthrie of Joint Sciences at the Claremont Colleges, a long-time friend of my husband, for reading and discussing the manuscript with me, and especially for editing the manuscript and facilitating its publication by the Southern California Academy of Sciences. Without him this publication would not have been possible. I also thank Peg Schultz, Director of Academic Computing, Pomona College and Eric Mann of the same department for their major help in preparing the manuscript for publication.

Alice S. Oglesby
March 31, 2005

The Salton Sea: Geology, History, Potential Problems, Politics, and Possible Futures of an Unnatural Desert Salt Lake

Larry C. Oglesby

Department of Biology, Pomona College, Claremont, California 91711

Introduction

The Salton Sea is the largest lake in California and second largest in the American West after the Great Salt Lake in Utah. The Sea is in the Colorado Desert of southeastern California in the bottom of the Salton Trough, the largest below sea level depression in the Western Hemisphere (See Fig. 1 for a political map of the Salton Sea area). The Salton Trough has been at various times a series of large freshwater lakes (the latest of which may have dried up as recently as 300 to 600 yr ago), a desert playa called the Salton Sink, and now a human-created and artificially-maintained saline desert lake. Marine incursions into this region took place only before the present below sea level depression developed.

The Salton Sea's quasi-marine ecosystem and trophic structure are unlike those found in any other body of water in the world, being based on benthic detritus formed by decaying plankton, and with the ecologically significant organisms all introduced from somewhere else, often from far away and usually accidentally. The hypereutrophic Sea harbors the most productive sport fishery in California if not the entire United States. The Sea, surrounding riparian habitats, and agricultural fields are an oasis of water, food, and cover attracting vast numbers of birds, especially wintering migratory waterfowl and shorebirds, but also summer rarities wandering north from México.

The present Salton Sea was created from 1905 to 1907 by illegal and inept agricultural water diversion from the Colorado River, but would be just the same size and chemical content today had its peculiar origin not happened nearly a century ago. From its lowest elevation in 1925 the Sea has risen more or less steadily to the present. Unless major and expensive intervention is successful, the probable future of the Salton Sea is for the salinity, 47 grams per liter (g l^{-1}) in 2000, (134% of ocean seawater of 35 g l^{-1}), to rise to a concentration that will prevent reproduction by the major sport fishes. As a consequence the most productive sport fishery in the state, with 1.5 million recreation days annually in the 1980s and an average catch of 1.5 to 1.9 fish per angler per hour (Black 1974; Black et al. 1985; Costa-Pierce and Riedel 2000), will collapse.

The number of campers at campgrounds in the Salton Sea State Recreation Area along the east shore has dropped by two thirds since the mid-1980s. The number of fishers similarly declined, apparently due both to negative publicity about unhealthy concentrations of trace elements, pesticides, and other pollutants supposedly in the sport fish and to rumors that the sport fishery is collapsing because fish cannot reproduce in the increasingly saline waters. Neither problem is in fact true. Pollution has never been a problem in the Salton Sea, and while there have been pessimistic predictions for the past 30 or 40 years that the sport fishery will soon collapse from increasing salinity, it has not happened yet. Bird hunter use of state and federal wildlife refuges near the Sea has declined more than the national average decline of 8% between 1980 and 1995 (Aiken 1999),

though sport bird abundance has not changed. Shoreline resort communities are not thriving, both because of reduced tourism and because rising Sea level has inundated houses, house trailers, motels, shops, marinas, jetties, roads, utility poles, and trees—which now pose navigational hazards as well as attracting fish and fishers.

A *Science* News Focus article in April 1999, alarmingly headlined "Battle Over a Dying Sea," quoted some biologists and wildlife managers to the effect that the Salton Sea was not worth keeping biologically viable because its problems were severe and incurable, but this widely read article did not even hint at the many decades of annual die-offs of fish and birds predating "alarming" die-offs in the 1990s, nor did it recognize that the Sea is not polluted (Kaiser 1999). A second news article by Kaiser (2000) was equally erroneously headlined, "Bringing the Salton Sea Back to Life." Hypereutrophic, the Sea is not now and never has been "dead"; rather it is burgeoning with life.

Novelist Joseph Wambaugh trashed the Salton Sea in his riveting 1992 mystery, *Fugitive Nights.* Wambaugh's protagonist, a disillusioned Palm Springs cop, is tailing what he thinks is a cheating husband to a desert tryst: "He was wondering why a rich guy like Clive Devon would hang around this dying place. Even the lowliest desert denizens had just about given up on the Salton Sea. That morning the wind was blowing a foul algae-sewage smell his way. The smell of red tide was blowing in his direction, and from a distance the polluted water looked like it had a crust you could walk on." deBuys (1999) painted a gloomy picture of major fish and bird die-offs in the 1990s from disease, pollution, and eutrophication. The Archaeological Conservancy's President Mark Michel (2000) called the Salton Sea "one of America's biggest ecological disasters." Much of the commentary on the World Wide Web about the Salton Sea is similarly pessimistic.

Are these worries justified? Probably not. Is the Salton Sea now an ecological disaster? Not yet. For example, here is Jim Matthew's Hot Spots section of his Fishing Report for 26 May 1999 in the Ontario CA *Inland Valley Daily Bulletin*: "SALTON SEA: The corvina bite exploded this past weekend over much of the sea with limits taking less than an hour, unless you were releasing the smaller fish. Five-fish limits typically weighed around [22.7 kg] total with a few over [4.5 kg] and a few under [4.5 kg]. Biggest fish reported in the [8.2 kg] class. The bite has spread over much of the sea. The tilapia bite is also awesome with catches of 150 to 200 tilapia a day common, especially in the northern half of the sea."

This review summarizes the geological setting and origin of the below sea level Salton Trough; formation of both Pleistocene and Holocene freshwater lakes (Lake Cahuilla); origin and history of the present Salton Sea; ecology of its biota including sport fish and birds; problems—both real and potential—faced by the Salton Sea and its biota; some possible futures; and federally-funded plans to "restore" or "save" the Salton Sea. Because the Salton Sea is totally dependent upon irrigation wastewater ultimately derived from the Colorado River and because many euryhaline biota move freely between the Sea and agricultural waters, the biology of these latter habitats will also be reviewed. For the same reason, the politics of agricultural water use, particularly in the Imperial Valley, must be discussed.

The many undocumented facts and ideas about aquatic ecology, anatomy, biology and ecology of the biota, and geology in this review derive from my teach-

ing research-focused courses in these topics at colleges, universities, and marine biology laboratories over four decades.

Geological Setting and Geological History of the Salton Trough

The Salton Sea lies in the bottom of a 7722 square kilometer (km^2) below sea level depression, the Salton Trough, in the Colorado Desert of southeastern California. It is the largest below sea level depression in the Western Hemisphere and second deepest, only 2 meters (m) less deep than California's Death Valley, but that part of Death Valley below sea level is much smaller in area (2124 km^2). The total drainage area of the Salton Trough into the Salton Sea is 32,300 km^2, but since the Salton Sea is fed almost entirely by agricultural wastewater from the Colorado River, its watershed is effectively that of the entire Colorado River (~934,000 km^2, or about 8.3% of the total land area of the continental US: Fradkin 1981) upstream from its last tributary, the Gila River that drains southern Arizona, part of New Mexico, and northern Sonora in México, and which enters the Colorado at Yuma AZ.

The Salton Trough is bordered on three sides (west, north, east) by mountain ranges, highest at the northern end and declining in elevation southerly on both east and west sides. The southern end of the Trough is composed of the low, broad fan delta of the Colorado River, separating the Trough from the Gulf of California (see Fig. 2).

The intensively cultivated Coachella Valley, northwest of the Salton Sea, begins at San Gorgonio Pass (sometimes called Banning Pass, 883 m) between the two highest mountains in southern California, Mount San Gorgonio (3450 m) and Mount San Jacinto (3288 m). To the south of the Sea is the even more intensively cultivated Imperial Valley, continuous with the Valle de Mexicali south of the Mexican border which extends southerly to the crest of the sedimentary delta dam. These three broad, nearly flat, "valleys" were not carved by river erosion, but constitute parts of the tectonically-created Salton Trough. The Trough is clearly a northwards extension of the axis of the Gulf of California (Sea of Cortez, Golfo de Cortés, Vermilion Sea). The Trough is narrowest (~20 km) at its northern end in the northern Coachella Valley and widens gradually to ~60 km at the international border.

Norris and Webb (1990) used the term Salton Trough (which they synonymized with Salton Sink) for the entire basin from San Gorgonio Pass to the Gulf of California, and restricted the term Salton Basin only to the region draining directly into the Salton Sea. No one else has adopted this confusing nomenclature, and the two terms (Basin and Trough) will here be treated as synonymous; the name Cahuilla Basin has sometimes been applied to the Coachella Valley. The term Salton Sink will be used only for the salt playa that occupies the bottom of the Trough when no lake is present.

The Salton Trough is separated from the Gulf of California by a broad low-conical alluvial dam composed of Colorado River sediments, with its gentle crest ~16 km wide (north to south) and ~60 km across (east to west) south of the Mexican border; its elevational apex is at Yuma AZ, 32 m (Fig. 2). The lowest point on the delta dam, on its western edge at Laguna Volcánica (Volcano Lake) in México a few km south of the California border, is only ~10 m above ocean sea level in the Gulf. At its fullest, Laguna Volcánica is up to 5 m deep, 16 km

by 9.6 km, and marshy (Cory 1913, 1915). The sediments of the delta came from the Colorado River's excavation of the Grand Canyon, a geologically-recent event that began during the Pliocene, 2 to 4 million yr ago (Lucchitta 1990); deltaic sediments in the southern Imperial Valley and Valle de Mexicali are up to 6.5 km thick (Winspear and Pye 1995; Hunter 1998a).

Geologist William Phipps Blake named the Colorado Desert in 1853, before Colorado itself became a state (Blake 1854, 1914a, 1915), a name he applied to the entire watershed of the Salton Trough and lower Colorado River in California, Arizona, Baja California, and Sonora (Lindsay 2001). The name is now generally restricted to the low desert west of the Colorado River in California. Biologically, the Colorado Desert of California is a northwesterly extension of the Sonoran Desert of northern México, southern Arizona, and southwestern New Mexico.

Recent volcanism, mud pots and mud volcanoes, carbon dioxide (CO_2) wells, hot springs, and numerous recent earthquakes all testify to the great geological activity of the Salton Trough. It is bounded and cut internally by many active faults, most notably the San Andreas Fault on the east side, the San Jacinto and Elsinore Faults on the west side, and a number of smaller faults in the Imperial Valley and Valle de Mexicali; all are right-lateral strike-slip faults (Fig. 3). The average right-lateral displacement on the San Andreas Fault system is 20–35 millimeters per year (mm yr^{-1}), but there is no current movement along that fault in the Salton Trough; rather, strain relief is shifted both east (to the East Mojave Shear Zone) and west (to the San Jacinto and Elsinore Faults, along with many subsidiary faults). Over 60 strong earthquakes have been reported in the Salton Trough since 1900; ~75% have been of M (Richter magnitude) 5.0 or greater, with one third of these over M 6.0; many of these quakes have involved the San Jacinto Fault (US Department of the Interior and The Resources Agency of California 1974a,b). Several large quakes have caused significant damage to buildings, roads, and irrigation structures. The largest in the 20th century, a M 7.1 quake on 18 May 1940 on the Imperial Fault, killed seven people, had a maximum right-lateral offset of 5.8 m, offset both the Mexican Alamo and US All-American Canals and the adjacent international border by 4.6 m, and caused vertical displacements of over 1 m (US Department of the Interior and The Resources Agency of California 1974a,b). A M 7.1 quake in 1892 on the Laguna Salada Fault (a southerly extension of the Elsinore Fault) west of Cerro Prieto in México caused a maximum vertical displacement of 3.5 m (Winspear and Pye 1995). Had current geothermal facilities been as fully developed prior to the last strong quakes (M 6.2 and 6.6 on 23 and 24 November 1987, on the Superstition Hills Fault southwest of the Sea) as they are now, they surely would have been seriously damaged, likely causing brine spills into agricultural drains and then into the Salton Sea. The west side of the Salton Trough and Baja California are on the Pacific tectonic plate, the east side of the trough and mainland México are on the North American plate. The many faults and earthquakes testify to the intensity and speed of the plates' movements relative to each other.

In addition to lateral offsets from fault ruptures, other geological hazards that must be addressed to protect the ecosystems of the Salton Sea and adjacent rivers, canals, and drains include ground shaking, unstable slopes, liquefaction, differential settlement and subsidence, and lateral spreading. Because of the active faults in the Salton Trough, many of the proposed projects to "restore" the Salton

Sea are within the state's Alquist-Priolo Special Studies Zone, in which special restrictions on development and construction apply (Salton Sea Authority and US Bureau of Reclamation 2000a).

Alluvial deposition from the Colorado River, meandering stream deposits, lacustrine deposits from Pleistocene and Holocene freshwater lakes (both central lake muds and coastal beach sands), alluvial and braided stream deposits shed from adjacent mountains, aeolian sand deposits, and present-day agricultural practices have all obliterated most direct surface manifestations of these faults on the floor of the Imperial Valley and elsewhere in the Salton Trough (van de Kamp 1973; Remeika and Sturz 1995). Elders et al. (1972) and Crowell and Sylvester (1979) discussed in detail the geological origin of the Salton Trough, which is only summarized here.

The east side of the Coachella Valley and Salton Sea is dominated by geological features associated with the San Andreas Fault system (Corona 1993a,b). A chain of rugged desert mountain ranges forms the eastern boundary of the Trough, only some of which are sketched in Fig. 1. From northwest to southeast these are: the San Bernardino, Little San Bernardino, Cottonwood, Orocopia, Chocolate, and Cargo Muchacho Mountains, and Ogilby Hills. The San Bernardino Mountains are the highest range in southern California, with summits from 3000 to nearly 3500 m. Summits in the more southerly ranges rarely exceed 1500 m and are mostly lower than 1000 m. Between eastside mountains and the Coachella Valley and Salton Sea is a linear array of low hills within the Salton Trough: the Indio, Mecca, and Durmid Hills, and the Algodones Dunes (Sand Hills, Imperial Sand Dunes) which extend across the border into México. These eastside mountains, low hills, and dune systems are aligned parallel with the San Andreas Fault. There are no equivalent low hills on the west side.

East of the Salton Sea itself the San Andreas Fault is only a single strand rather than the splay of sub-parallel faults further northwest in the Coachella Valley and San Gorgonio Pass (Dibblee 1977). This single southernmost strand of the San Andreas Fault, extending southeast from the convoluted and strongly eroded Indio and Mecca Hills, has been seismically inactive in recent times. Sieh and Williams (1990) presented evidence for several major quakes on the Indio fault segment in the last 1000 years (yr), the most recent of which occurred ~300 yr ago. The southernmost point where surface manifestations of the San Andreas Fault can be seen is at Bat Caves Buttes at the southern end of the Durmid Hills. Just north of Bat Caves Buttes, Salt Creek (sometimes called Salton Creek) enters the Salton Sea, draining a large watershed extending well east of the Orocopia and Chocolate Mountains. In wetter times Salt Creek formed a large alluvial fan that now composes much of the east shoreline of the Salton Sea. Salt Creek is offset 850 m by the San Andreas fault just ~0.3 km upstream from State Highway 111, the railroad bridge, and the creek's mouth into the Salton Sea, and is incised as much as 40 m into its alluvial fan due to recent uplift along the axis of the fault (Baldwin et al. 1997).

The Durmid Hills north and south of Salt Creek are composed of soft lacustrine deposits dating only to the Pleistocene, much deformed into a system of east-trending folds arranged in a right-stepping *en echelon* pattern oblique to the northwest-southeast axis of the San Andreas Fault (Dibblee 1997; Burgmann 1991; Corona 1993a,b; Baldwin et al. 1997). The Durmid Hills are a rising anticline

whose axis is parallel to the San Andreas Fault and whose rapid present-day uplift is demonstrated by its youthful drainage pattern. Direct measurements showed the Durmid Hills rising at the rate of 1 mm yr^{-1} between 1985 and 1987. This rate has persisted over the past ~1 million yr, based on stratigraphic studies of the 40 m incision of Salt Creek (Sylvester 1988; Sylvester et al. 1993) and the known age of a layer of Bishop Tuff. The white Bishop Tuff (rhyolite ash) is an aerial deposit from a massive volcanic eruption of the Long Valley caldera on the east side of the Sierra Nevada south of Lake Tahoe ~760,000 yr ago (Burgmann 1991); it is exposed in complex folds both in the Mecca Hills to the northeast of the Salton Sea (M. Rymer, pers. comm.; Oglesby pers. obs.) and in the Coyote Badlands of Anza-Borrego Desert State Park to the southwest of the Salton Sea (M. Rymer 1991, pers. comm.; Corona 1993a,b). Curiously, the Durmid Hills uplift stopped completely after the M 7.3 June 1992 Landers earthquake well to the north in the Mojave Desert (M. Rymer pers. comm.). Following that quake there was "sympathetic" right lateral movement (triggered slip) of the San Andreas Fault in the Coachella Valley, creating small dextral surface breaks discontinuously over 54 km from the Indio Hills to Bat Caves Buttes, with some minor vertical slip in the Mecca Hills. These slips occurred within one minute of the Landers mainshock. Dextral triggered slip had been observed in this same area from three recent large earthquakes in the Imperial Valley and northern Coachella Valley (M. Rymer 2000, pers. comm.).

It is now believed that the San Andreas Fault itself has its southern terminus just south of Bat Caves Buttes, with a 40 km gap separating it from the northern end of the Imperial Fault to the southwest. The several faults in the Imperial Valley between the southern end of the San Andreas Fault on the east side and the westside San Jacinto and Elsinore Faults step *en echelon* across the southern Salton Sea, Imperial Valley, and Valle de Mexicali from northeast to southwest. In this 40 km gap is the northernmost crustal spreading center (pull-apart zone) of the East Pacific Rise, here called the Brawley Seismic Zone (Fig. 3). This fault gap generates earthquake swarms and displays strong geothermal and volcanic activity. A flurry of small earthquakes in October and November 1999 at the southern end of the San Andreas Fault was apparently triggered by the M 7.1 October 1999 Hector Mine earthquake epicentered east of the Landers quake epicenter in the Mojave Desert (Hunter 2000; Scientists of the US Geological Survey 2000). Later, a swarm of over 30 small earthquakes (the largest M 4.3) took place on one day near the southern terminus of the San Andreas Fault at Bat Caves Buttes. Quake activity continues near Obsidian Butte, ongoing since 1989 (Scientists of the US Geological Survey 2000).

Together, these geological activities demonstrate a major change in crustal deformation processes, a transition between the San Andreas right-lateral strike-slip system to the ridge-transform system of the East Pacific Rise in the Gulf of California—one of the few places on earth where zero age crust is being created at an active plate margin within a continent (R. D. Brown 1990; Herzig and Jacobs 1994; Johnson et al. 1994; Glockhoff 1998). The next southerly crustal spreading center of the East Pacific Rise underlies the Cerro Prieto volcanic area on the west side of the Valle de Mexicali (Fig. 4); the next one south of Cerro Prieto is under the very northern Gulf of California (Elders 1979c; Irwin 1990; Corona 1993a,b; Remeika and Sturz 1995; Residencia General de Cerro Prieto 1998).

Evidence indicates that the East Pacific Rise and Gulf of California rift system are actively extending northerly in the Salton Trough (Larson and Reilinger 1991).

At the southeast end of the Salton Sea, within the Brawley Seismic Zone, are five Holocene volcanic buttes in a northeast-southwest alignment, rising 35 to 40 m above the valley floor (Fig. 1). Their current names (from northeast to southwest) are Mullet Island (−57.9 m), Red Hill (−41.8 m) joined with Alamo Butte (−38.7 m), Rock Hill (−41.5 m), and Obsidian Butte (−36.9 m), but other and often confusing names have been used for them in the past; the name Obsidian Butte has been used for at least two different buttes as well as for the entire group of five. Cahuilla Chief Francisco Patencio and ethnographers such as Bean used the names Paint Island, Pelican Island, Three Buttes, and Mullet Island, but how these four older names translate to the five present buttes is not known (Patencio 1971; Bean et al. 1991). The buttes were formed between 55,000 and 2000 yr ago, either as underwater extrusions of magma (Red Hill) or as single aerial explosions (Obsidian Butte, Rock Hill) (Kelley and Soske 1936; Muffler and White 1969; Robinson et al. 1973; Elders 1979c; Hunter 1998a). Norris (1995b) concluded, "The Obsidian Buttes are probably only a few thousand years old, at most." When Lake Cahuilla was at its still-stand elevation of ~10 m above ocean sea level (see below), these buttes would have been completely submerged. At the high point of the new Salton Sea in 1907 all five buttes were islands; since then, the four southern buttes were re-connected to the mainland by desiccation of the Salton Sea. The four southern buttes would in 2000 all be islands, but are connected to the mainland by raised road dikes (Oertle 1964; Oglesby pers. obs). Land access to Mullet Island was cut off by rising Salton Sea waters in the 1940s and the buildings on it abandoned.

Tufa (calcium carbonate [$CaCO_3$]) deposits occur on all five buttes, indicating that they were covered by at least one iteration of Lake Cahuilla (see below). The buttes are composed of acidic rhyolite and several have obsidian flows; active fumaroles occur on at least three buttes (Oglesby pers. obs.). These buttes were a major source of obsidian for Indian arrowheads throughout southern California (Patencio 1971; Koerper et al. 1986; Salton Sea Authority and US Bureau of Reclamation 2000a); they are also the source of the pumice ("the rock that floats") that washes ashore all around the Salton Sea. Between 1934 and 1972, Red Hill moved southeast ~15 centimeters (cm), (0.4 mm yr^{-1}), relative to Obsidian Butte (Hunter 1998a), a right-lateral slip in the Brawley Seismic Zone that did not involve active seismicity. Elders (1979c) concluded that the processes operating to form the five buttes were consistent with those operating at oceanic crustal centers.

A resort called Hell's Kitchen, named for nearby mud volcanoes, was started on Mullet Island in 1908 and lasted into the 1930s. de Stanley (1976) paraphrased a 1852 report by a Major Hutchinson: "a great eruption of hot water and mud, with jets of steam, issuing from conical hillocks. Masses of dark-colored mud were thrown to a height of [12.5 m]." Patencio (1971) described them: "There were acres of boiling mud springs all around. They were very hot. They boiled and hissed. No one could get close to them, for the ground was very sticky and the air was poisoned with gas. The hot gray mud piled on itself until it rose [5.1 to 6.7 m] in the air. Then it fell, to build up once again. The steam rises from

the center of the mud stacks and at the top, mud could be seen jumping and whirling. Many lives have been lost going too near them. The crust of the ground breaks under one's feet. One is apt.to disappear into the hot mud forever. The Indians called the place *Par-Powl,* which means water bewitched, and they stayed away." No terrestrial mud volcanoes in the Salton Trough are remotely this active today; the Mullet Island field is now under water. Geothermal exploration began near Mullet Island in 1927 (Wynn 1975) but was soon abandoned because of the highly saline and erosive groundwaters brought to the surface.

The Cerro Prieto area just south of the Mexican border on the west side of the sedimentary deltaic fan is volcanic, with Laguna Volcánica, on the low point (elevation ~10 m) of the broad crest of the delta dam, being named for this feature (Figs. 2 and 4). Volcán Cerro Prieto (a basalt cinder cone, 260 m) has not erupted in historic times, but based on the lack of erosion of the cone after its last eruptive event, must be youthful (Elders 1979c; Lindsay and Hample 1998). The Cerro Prieto area has active mud pots and mud volcanoes, hot springs, and geothermal fields, commercially exploited beginning in 1958 (Residencia General de Cerro Prieto 1998). Glowacka and Nava (1996) proposed that withdrawal of geothermal fluids from the Cerro Prieto field triggers sometimes significant earthquakes in the region, including a M 6.6 quake on the Imperial Fault in October 1979.

In the volcanic buttes area at the southern Salton Sea, ~50 CO_2 wells (the Imperial Carbon Dioxide Gas Field), reaching depths of 152 to 213 m, were in production from 1934 to 1954; two processing plants converted recovered CO_2 gas to dry ice (Rook and Williams 1942; Lande 1979; Vedder et al. 1993; Baldwin et al. 1997; Sturz et al. 1997, 1998; Hunter 1998a). A few capped CO_2 wells, mud pots and mud volcanoes, and deserted, flooded buildings can still be seen along Davis Road, a bleak and surreal vista. A small group of active mud pots and volcanoes is located ~2 km south.

Groundwaters brought to the surface by pressurized CO_2 in these mud pots and mud volcanoes vary considerably in temperature, salinity, water level, amount and color of mud, and growth of bluegreen algae (cyanobacteria), other bacteria, and halophytic vascular plants (Oglesby pers. obs.). Water boatmen (*Trichocorixa reticulata*) inhabit some pools (Oglesby pers. obs.). Salinity varies from nearly freshwater to as much as 108 g l^{-1} Temperatures are usually relatively cool, 12 to 32°C, reflecting ambient air temperatures. Temperatures as high as 40 to 60°C are characteristic of those mud volcanoes with the most vigorous venting (Sturz et al. 1998; Oglesby pers. obs.). Activity, temperature and salinity vary both seasonally and over longer periods of time (Sturz et al. 1998; Oglesby pers. obs.). There are two fluid sources, surface groundwater and deeper geothermal water; different mud volcanoes and pots vary in the relative proportions of the two water sources (Sturz et al. 1998).

A large salt playa occupies the closed and somewhat below sea level Pattie Basin to the southwest of Cerro Prieto on the west side of Sierra de las Cocopás (Cocopah Mountains), called Laguna Salada (Mexican name) or Laguna Maquata (Indian name) (Figs. 2, 4, and 5; Sykes 1914, 1937; Carpelan 1961a; Elders 1979c). Laguna Salada, when filled with water to its maximum elevation, is ~64 km by 32 km and is supposedly occasionally filled by extremely high tides (~10 to 13 m) in the northern Gulf of California (Residencia General de Cerro Prieto 1998). Laguna Salada also receives agricultural wastewater from México.

The southern end of the Salton Trough (Imperial Valley and Valle de Mexicali) lacks a mountain rim, being formed by the low, broad delta fan of the Colorado River (Fig. 2). The gradient sloping north here is very shallow, as low as ~0.1 m km^{-1}; as a result, even a small change in Salton Sea elevation covers or uncovers a great extent of land area. Small mountain ranges are rather far to the southwest, such as the Sierra de las Cocopás (Figs. 2 and 5), whose northernmost peak is the conspicuous Signal Butte (689 m; also called Signal Mountain or Mt. Signal) in México just south of the US border, and the Coyote Mountains and Superstition Hills in California.

The geology of the west side of the Salton Trough is markedly different from that of the east side (Remeika and Linsley 1992; Remeika and Sturz 1995). In brief, Anza-Borrego Desert State Park and the southwestern end of the Salton Trough are dominated by the Western Salton Trough Detachment. Detachment faults (listric, or concave, faults) are steep normal faults at the surface. As they deepen and here extend to the east, the fault planes curve and become increasingly parallel to the surface and fracture into distinct bedrock faults which subside domino-style into the Salton Trough. This process forms a parallel series of ridges separated by half-graben basins: the hanging wall of the western side of each half-graben is the footwall of the next one east. Remeika (1995b) stated that this "tectono-sedimentary behavior of progressive basinward stepping-down of bounding faults" from west to east is strong evidence of crustal extension. Axen and Fletcher (1998) and Lough (1998) described in detail the Anza-Borrego and Laguna Salada detachment fault systems.

The Santa Rosa Mountains to the north of Anza-Borrego Desert State Park dominate most of the west side of the Salton Sea (Fig. 1); the highest summit, Rabbit Peak, is 2160 m. The Santa Rosas are partly formed by detachment faults and partly by right-lateral strike-slip movement along the San Jacinto and Elsinore Faults, both west of the Santa Rosas (Fig. 3; Remeika 1995b). The San Jacinto fault shows the greatest accumulation of surface strain in this area, strain which increases to the southeast as it enters the Imperial Valley. The San Jacinto fault seems be taking up the strain of the San Andreas Fault which dominates to the east (Johnson et al. 1994; Miller 2000b). The steep eastern scarps of the Santa Rosa and San Jacinto Mountains, both with long rocky spurs extending eastwards into the Coachella Valley, such as Travertine Rock (Travertine Point) at the northwest end of the Salton Sea and several even larger spurs to the north, do not seem to be fault controlled. Evidence suggests that either these ranges were arched up by compression or else tilted northeastward from the San Jacinto Fault as the Coachella Valley subsided and filled with sediments (Dibblee 1997).

Origin of the Below Sea Level Salton Trough and its Pleistocene and Holocene Lakes

Conspicuous beachline features on the lower slopes of the Santa Rosa Mountains west of the community of Desert Shores testify to the former presence of a very large body of water, one that occupied the Salton Trough north of the Colorado River delta, called Lake Cahuilla. The popular story is that Lake Cahuilla was initially formed by deposition of the Colorado River sedimentary delta across a seawater-filled below-sea-level depression (the Salton Trough), blocking off ocean access to the northern Gulf of California and isolating a ~8500 km^2 ocean

seawater lake which then gradually dried up, leaving the conspicuous shorelines at ~10 to 12 m above ocean sea level. This story is perpetrated in the popular and semi-popular press and popular (but not geological) guidebooks to the Salton Trough, by several major water districts, in programs at the Visitor Center at the Salton Sea State Recreation Area, and in semi-popular, scientific, and government publications (e.g., Usinger 1958; deStanley 1976; Imperial Irrigation District Public Information Office 1998b; Laflin 1995, 1998). From looking at maps or space photos, this scenario seems plausible. As a typical example, Pomento (1998), writing for the Metropolitan Water District, wrote: "Historically, the Salton Sea, or more accurately the Salton Sink, was part of the Gulf of California that extended north to a few miles above the town of Indio, about [230 km] from its present northernmost reach. For centuries, the Colorado River has carried a heavy silt load that gradually created an immense, broad, fan delta that cut off the northern end of the gulf, leaving the Salton Sea [*sic*], the bottom of which lies [91.2 m] below sea level, to evaporate." This story is not true, even though it was espoused by some early geologists (e.g., Blake 1854, 1914; Sykes 1914). Even recently, Pepper (1999) and deBuys (1999) as well as federal agencies such as the Salton Sea Authority and US Bureau of Reclamation (Salton Sea Science Subcommittee, 2000), adopted Blake's incorrect 1854 version. As described below, the growing Colorado Delta did not post-date but coincided with subsidence forming the Salton Trough. There is no geological or paleontological evidence for the northern part of the Gulf of California being cut off by the growing delta, leaving a ocean-saltwater lake to desiccate.

An early geologist (Free 1914) advocated a different explanation for the origin of the below sea level Salton Trough, one that is now generally accepted by geologists. As the alluvial Colorado River delta sediments, derived from excavation of the Grand Canyon beginning during the early Pliocene, accumulated to their present great depth, the proto-Salton Trough to the north of the broad delta gradually subsided below sea level as a direct consequence of crustal spreading (Free 1914; McKibben 1993; Howard 1996; Hunter 1998a), forming a probably-dry below-sea-level depression. Maximum Colorado River sediment depths are as much as 8040 m (8.04 km) just south of Mexicali, and >3000 m (3 km) throughout most of the Salton Trough (Winspear and Pye 1995; Hunter 1998a; Salton Sea Authority and US Bureau of Reclamation 2000a). Only later did freshwater lakes (Lake Cahuilla) fill this below sea level depression.

The last marine incursions into the pre-Salton Trough from the proto-Gulf of California occurred in the late Miocene or early Pliocene, at least 4 million yr ago. There are marine fossils in the late Miocene/early Pliocene, stratigraphically complex Imperial Group composed of the Latrania Formations, Coyote Mountain Clays, and the Yuha Formation (Remeika 1998), e.g. oysters (*Pycnodonte heermannii,* up to 0.3 m long, and the smaller *Dendrostrea vespertina*), as well as other bivalves in the well-known Yuha oyster beds, all located some 300 m above present ocean sea level. These were recognized as early as 1775 by Padre Pedro Font of Anza's second expedition of 1775 to 1776. Font hypothesized that the ocean had once extended this far north, as did Blake in 1853 (Blake 1854, 1914; Watkins 1990a; Remeika 1998; Lindsay 2001). These uplifted marine beds have been much studied in Anza-Borrego Desert State Park as well as in other parts of the Salton Trough (Sylvester and Smith 1976, Remeika and Sturz 1995; Powell

1995; Remeika 1995b; Whistler et al. 1995; Frost et al. 1997; Remeika 1998). Many popular and semi-popular writers state that the Yuha oyster beds document a recent seawater incursion into a below sea level Salton Trough from the Gulf of California, but these Miocene marine beds are in fact much higher than present ocean sea level, and have no relevance to any recent marine incursions, which geologists do not accept. Marine invertebrate fossils found in recent deposits, including the late Pleistocene, are reworked from older deltaic deposits (Remeika 1998). A below sea level Salton Trough did not exist during Miocene times (Glockhoff 1998; Remeika 1998).

Beginning at about the same time, the Baja California peninsula became increasingly separated from mainland México through tectonic movements of the Pacific Plate relative to the North American Plate, opening the proto-Gulf of California from south to north, a process that is ongoing. Remeika and Linsley (1992) wrote, "Commencing about 5 million yr ago, the Gulf of California unzipped like a horseshoe opening to the south, with the tip at Cabo San Lucas rotating [237 km] away from the Mexican mainland." The Colorado River reached its present ~1550 m depth in the Grand Canyon only ~1.2 million yr ago (Remeika and Fleming 1995). Remeika (1995a) wrote that the Salton Trough is "downdropped by faulting that is [also] rafting Baja California away from mainland México." The Salton Trough (including the Coachella Valley, Salton Sea, Imperial Valley, and Valle de Mexicali), Colorado Delta, and Gulf of California form a large graben, a subsided area between the Pacific and North American tectonic plates (Remeika and Fleming 1995; Howard 1996; Glockhoff 1998; Remeika 1998).

The crest of the delta, at its lowest point at Laguna Volcánica in México, showed a net tectonic rise (uplift) of ~1.5 m from 1926 to 1978, forcing the Colorado River further away from the Salton Trough and towards the Gulf (Gilmore and Castle 1983). Precise geodetic surveys since 1972 show that the Imperial Valley crust continues to be significantly deformed; there is a downward regional tilt from just south of the Mexican border to the Salton Sea, both deepening and widening the Salton Trough at rates of 3.5 to 4.0 cm yr^{-1} (Lofgren 1979b). At the time of Lofgren's study, geothermal fluid extraction had not developed sufficiently to cause soil subsidence in the Imperial Valley. As a result of continued tectonic spreading and subsidence, gradients of streams, canals, and drains in the Imperial Valley are steepening, and the capacity of the Salton Sea is increasing. Not all the drowning of agricultural lands and shoreline structures at the edge of the Sea is caused by rising Sea level—some is due to continuing subsidence of the land surface (Lofgren 1979b; Glockhoff 1998; Hunter 1998a; Miller 2000b).

The closed basin of the Salton Trough has been repeatedly filled by bodies of fresh water for at least 50,000 yr, many of them to the same still-stand elevation—roughly the elevation of the low point of the Colorado delta dam, ~10 to 12 m. These large lakes (~92 m deeper and 10 times the area of the present Salton Sea) are usually called Lake Cahuilla (Figs. 1 and 4). They were fresh water at the times of their formation and while they were full and out-flowing to the Gulf. They would eventually become saline as they desiccated (Cagle 1998).

There are conspicuous and diverse shoreline features, such as sand and gravel beaches, wave-cut cliffs as high as 7 m, shingle terraces of small smoothed rocks,

sand spits, and bay-mouth bars, all around the Salton Trough at approximately the same elevation (~10 to 12 m), testifying to the presence of these large and long-lasting lakes, ~8500 km^2 in area, extending from near Palm Springs to south of the Mexican border (Figs. 1 and 4). The tips of the Durmid Hills, including Bat Caves Buttes, would have formed a series of small islands in Lake Cahuilla (Sykes 1914; Maloney 1986; Winspear and Pye 1995; Oglesby pers. obs.). Winspear and Pye (1995) attributed the sand supply of the Algodones Dunes to blow sand from the shorelines of Pleistocene Lake Cahuilla and later lakes, ultimately derived from the Colorado River sediments.

The most spectacular place to see this impressive fossil shoreline is on the east-facing base of the Santa Rosa Mountains just west of Desert Shores, to the west of the present north Salton Sea shore. Above a conspicuous horizontal shoreline on the rock slopes, where tufa deposits below end and naked cliffs above begin, the reddish desert varnish has been eroded off the gray and tan granite cliffs by wave action; this erosional feature is particularly evident on what would have been rocky promontories extending out into the lakes. Below the horizontal shoreline, cliffs and rocks are covered with tufa deposits like cake icing; this tufa is locally called "travertine," or, even more inaccurately, "coral," but is formed by quite a different process.

Tufa is a freshwater deposit of $CaCO_3$ requiring photosynthetic bluegreen bacteria in a warm, hardwater lake; the bluegreen alga *Calothrix* is often implicated in tufa deposition. Bluegreens do not actually *secrete* $CaCO_3$ (thus, they are not like coralline algae), but their photosynthetic activities enhance precipitation of $CaCO_3$. Tufa deposits above Desert Shores and at Travertine Rock are as much as 1 m thick, and within overhangs show evidence of growth upwards towards light; these tufa deposits were described in some detail by Jones (1914).

Radiocarbon dating indicates that the major layers of tufa in the Salton Trough were deposited primarily during the Pleistocene, beginning ~17,590 yr ago, with the main deposition period ending about ~7205 yr ago, but tufa deposition continued during the Holocene whenever a lake was present. Repeated deposition of tufa layers was so regular that the designs of petroglyphs (incised Indian rock designs) were transmitted to the most recent tufa surface; these petroglyphs have been dated up to about ~9000 yr ago (MacDougal and Sykes 1915; Reynolds and Turner 1971). Photographs of petroglyphs in tufa are in Laflin (1998) and deBuys (1999). In both photos the locations are not identified and the petroglyphs look like they were incised directly into the tufa and not carried through from the underlying rock during later tufa deposition. Unfortunately, the fine display of tufa and petroglyphs on Travertine Rock has been largely destroyed by vandals with spray paint (Lindsay 2001; Oglesby pers. obs.). Indian artifacts recovered from below the still-stand line of the most recent Holocene lake(s) often have thin tufa deposits (Oglesby pers. obs.). Jones (1914) described $CaCO_3$ deposition (tufa, since *Calothrix* filaments were present) on drowned shrubs and the volcanic buttes by the desiccating but still low-salinity Salton Sea during the first years after its initial formation in 1905 to 1907. In the present Salton Sea 95 yr later, gypsum (calcium sulfate [$CaSO_4$]) precipitates out before $CaCO_3$, because of different solubilities in this now saline lake (D. Zenger pers. comm.; Oglesby pers. obs.).

Desiccating lakes, including the present Salton Sea at times (Oglesby pers.

obs.), form erosional cliffs and broad, level beach terraces during the winter still-stand, terrace width depending on the steepness of the slope. During summer's rapid evaporation, these beach terraces are marooned above water level. If there is no significant inflow, such as when the Colorado River abandons the Salton Trough and flows directly to the Gulf of California, these recessional cliffs and terraces are spaced ~1.8 to 2 m vertically apart, reflecting the high evaporation rate in this intensely hot, arid climate. The Durmid Hills and all five volcanic buttes have (or had, before quarrying) conspicuous recessional terraces; thin layers of tufa ($CaCO_3$) coat much of the most recent obsidian and rhyolite. Recessional features on the four buttes reachable by road have been severely damaged by recent quarrying (Oglesby pers. obs.). Recessional terraces on less steep slopes are easily recognized from the air (Corona 1993a,b; McKibben 1993; Oglesby pers. obs.). These terraces were presumably created during desiccation of the most recent large lake to occupy the Salton Trough, whose desiccation dates to 300 to 600 yr ago.

Studying ~2 m yearly recessional terraces formed during the initial desiccation of the Salton Sea right after its formation in 1907, MacDougal (1914b) observed that desert shrubs germinate preferentially at the moister, more shaded, bases of these little cliffs, creating lines of shrubs growing on contours. Vegetation contour alignments can still be seen on recessional shoreline topography around the present-day Salton Sea (Oglesby pers. obs.), including the Durmid Hills and Bat Caves Buttes. One of the best places to have seen desert shrubs growing on successive contour intervals in the past was from the top of Travertine Rock, looking out on the sand bar that connected it to the main mass of the Santa Rosa Mountains. Travertine Rock would have been a tombolo when Lake Cahuilla was full. Planting of vineyards in 1985 and long-time infestation by off-road vehicles have obliterated all native vegetation and the recessional beach terraces on which they grew on this large sand bar (Oglesby pers. obs.). During the past 30 yr and more, with the Salton Sea elevation more or less stabilized, the same pattern of cliff and terrace forms yearly, with successive terraces only a few cm apart vertically, drowned and eroded during the next high water period in late spring.

Myriad fossil freshwater mollusc shells litter the uncultivated desert surface below the Lake Cahuilla shoreline all over the Salton Trough, blown by the wind and consolidated several meters deep in washes. Their abundant presence is perhaps commemorated in the name Coachella, which may be a corruption of the Spanish *conchilla,* meaning "little shell" (Pepper 1972, 1999; Nordland 1978; Laflin 1998). A second hypothesis for the name Coachella is that it is a variant spelling of Cahuilla or Coahuilla (e.g. Nordland 1978; Laflin 1998; deBuys 1999). A third possibility for the name is that it is artificial, made-up from COA(huilla) and (con)CHILLA (Nordland 1978; Laflin 1998); Laflin considered this third explanation the most likely. The most common fossils (Table VI) are the tiny, long-spired prosobranch *Tryonia protea,* the larger and more globular pulmonate *Physa virgata,* and the swan mussel *Anodonta californiensis.* Only fragments of *Anodonta* shells are found where people have access, as they are very fragile. Intact *Anodonta* shells, some even articulated, may be found in places where people seldom go, such as the Navy's Salton Sea Test Base on the southwest shore of the Sea (Oglesby pers. obs.). Whistler et al. (1995) listed these and other freshwater mollusc species (Table VI), as well as diatoms, sponges, and ostracods,

found in trenches dug through lacustrine sediments northwest of the present Salton Sea, below the conspicuous Lake Cahuilla shoreline. These freshwater mollusc fossils are embedded in tufa deposits, further indicating the freshwater origin for tufa deposition. Those molluscs listed in Table VI still living in the southwestern US live in freshwater to slightly saline environments. Blake (1857, 1914) recognized these as freshwater shells, but some more recent authors, though following Blake's geology, erroneously call the fossils marine (e.g. Laflin 1998). Clearly, the several bodies of water in the Salton Trough in which these fossil molluscs lived were freshwater, not marine, including both Pleistocene and Holocene lakes, as pointed out by Blake (1914), Free (1914), and many others.

A restricted marine fossil fauna is found in the Salton Trough below −61 m (Van de Kamp 1973). These marine fossils do not indicate flooding of the Salton Trough by an incursion of the Gulf of California. Rather, high salinities of desiccating small remnant lakes at the bottom of the Trough permitted temporary survival and reproduction of marine mud flat organisms brought in from the Gulf by birds and other overland transport mechanisms (Van de Kamp 1973).

Elders (1979c) described the currently accepted explanation for both the series of Pleistocene and Holocene lakes in the Salton Trough and the fact that the Colorado River normally empties southerly across its broad delta into the Gulf of California: "When the river flowed to the Gulf, it graded its bed to [ocean] sea level. There was, therefore, a greater gradient to the *north* to the closed basin [Salton Trough]. In times of flood, when the river topped its levees, any distributaries which flowed north could capture the flow. Thus the basin filled until over the low point of the crest of the delta [~10 m at Laguna Volcánica]. The river then graded its bed to the elevation of the lake it had created, ~11 m above sea level. At this point the gradient south to the [Gulf] would be steeper than that to the north. Consequently in times of flood, when the river topped its levees, any distributaries which flowed *south* could capture the flow. Thus the delta oscillated between two metastable conditions." The overflow of full-stand lakes in the Trough to the Gulf of California was apparently by way of the Río Hardy, the westernmost major distributary of the delta. Winspear and Pye (1995) estimated that it would have taken 10 to 20 yr for a northwards-flowing Colorado River to fill a Lake Cahuilla to the elevation of the ~10 m shoreline, and ~60 yr to desiccate under present climatological conditions. They pointed out that there is no correlation between the geological record of major Colorado River floods (Ely et al. 1993; O'Connor et al. 1994) and fillings of Lake Cahuilla; rather, the gradient of the fluvial channel and perhaps tectonic movements are more important.

Remeika and Linsley (1992) observed that the southern side of the delta dam is being actively eroded by the great tidal range of the northern Gulf of California, especially recently as the many dams on the Colorado River prevent most deltaic silt deposition. They predicted that the delta dam, composed of soft sediments, will eventually be breached by the Gulf, which will then invade the Salton Trough, drowning the Valle de Mexicali, Imperial Valley, and Coachella Valley, and turning Palm Springs into a beach city; they are in no immediate danger.

Geologist William Phipps Blake was the first to recognize the geological evidence for a very large prehistoric lake in a below-sea level Salton Trough, in 1853 while scouting for the best route for the Southern Pacific transcontinental railroad (Blake 1854, 1857, 1914, 1915; Hoyt 1990; Remeika 1998). He was the

first Euro-American to recognize that the low and comparatively gentle San Gorgonio pass was the best route to the coast in all California; despite the rigors of the desert, this route avoided the Sierra Nevada and other mountains. Blake listened to Desert Cahuilla stories which recounted in some detail a vast lake ("*agua grande*"), filled with fine fish ("*pescados finos*"), and which dried up little by little ("*poco-a-poco*" [Blake's hyphens]), and which Blake calculated must have been present as recently as 400 to 600 yr before 1853. This Holocene lake of the Desert Cahuilla oral traditions was much more recent and temporary than the long-lasting Pleistocene lakes which constructed the impressive shoreline features. Blake named this most recent of the ancient lakes Lake Cahuilla in 1909. Separate names have sometimes been given to the more temporary Holocene lakes, to distinguish them from Pleistocene Lake Cahuilla, including Blake Sea and Lake LeConte, but these names are not used consistently, and all three names have been applied both to the long-lasting Pleistocene lakes and to the several more ephemeral Holocene lakes. The present-day Lake Cahuilla is a small reservoir on the west side of the Coachella Valley, the terminus of the Coachella Canal.

Several Indian groups made extensive use of the Salton Trough. Both the easternmost of the Western (or Pass) Cahuilla and the Desert Cahuilla, of the Uto-Aztecan (Shoshonean) linguistic group, were resident in the Coachella Valley, having arrived from the north and northeast ~1000 to 2500 yr ago. Desert Cahuilla maintained permanent villages on both sides of the southern Coachella Valley south nearly to the Imperial Valley, near springs and fan palm (*Washingtonia filifera*) oases along traces of the San Andreas Fault splay on the east side, and at the mouths of canyons on the west side, where there was reliable water. Western (Pass) Cahuilla maintained villages on the western side of the Coachella Valley north and west from Palm Springs, especially near fan palm groves in mountain canyons. Cahuillas traveled seasonally from the low desert to higher elevations to take advantage of diverse seasonal food supplies, often using regular camping sites. There is considerable controversy over the origin of the name "Cahuilla" (Kroeber 1925; James 1960; Bean 1972; Bean and Saubel 1972; Bean et al. 1991; Lindsay 2001).

The high water table in the southern Coachella Valley, derived from groundwater runoff from the San Bernardino and San Jacinto Mountains, meant that the valley provided ready access to water. The Desert Cahuilla was the only California group to dig water wells, usually reached by a ramp or series of steps; at least 10 wells have been recorded (Bean et al. 1991; Schaefer 1998). A photograph of an 8.2 m deep stepped well was taken before the area was damaged in the great flood of 1916 (photo reproduced by Nordland 1978, Dozier 1998, Laflin 1998; the dates of this one photo are different in the three different sources). The Desert Cahuilla irrigated crops using water from mountain streams brought out on the desert floor by stone ditches (Bean and Saubel 1972; Laflin 1998); they may have also irrigated with water from springs and artesian wells (Laflin 1998). The Cahuilla cultivated such Mesoamerican crops as squash, melons, beans, maize, and barley, the only California Indians known to have done so (James 1960; Bean 1972; Bean and Saubel 1972; Dozier 1998; Schaefer 1998).

Other tribes, including the Kumeyaay (Quemeya and many other spellings; also called Eastern Tipai and Southern Diegueño), Cocopa (Cocopah, Cucapá), and Quechan (Yuman), all of the Yuman linguistic group, occupied the Salton Trough

south of the Salton Sink, the west side of the lower Colorado River, and northern Baja California, having arrived ~1500 to 2000 yr ago. The Kamia were the most desert-adapted of the Kumeyaay (Schaefer 1998). The Kamia occupied part of the riparian corridor along the New River, and made seasonal use of the Imperial Valley, including flood plain agriculture along the New River, perhaps growing maize, squash, melons, and beans like the Desert Cahuilla (Kroeber 1925; Bean and Saubel 1972; Schaefer 1998; Lindsay 2001).

On the west side of the Salton Trough the border between Kumeyaay and Cahuilla was somewhere between San Sebastian Marsh on San Felipe Creek (elevation −10 m), where there was a large Kumeyaay village when no Lake Cahuilla was present, and Desert Shores near Travertine Rock. The two groups interacted extensively, though this would have been difficult when Lake Cahuilla was full, as the still-stand shoreline is on steep mountain slopes, forcing travelers to trails on the cliffs (Schaefer 1998; von Werlhof 2001.

The Cahuilla and other groups exploited the shoreline of one or more iterations of the Holocene Lake Cahuilla. von Werlhof (2001) described what Cahuilla life might have been like when Lake Cahuilla was present. He speculated that the northern portion of Lake Cahuilla was "stagnant" and that the Cahuilla were able to take advantage of that situation. But it is highly unlikely that a large, deep lake such as Lake Cahuilla would have reduced horizontal circulation, even if it did stratify during summers (Hutchinson 1975). Whistler et al. (1995) found a diverse array of molluscs and other fossils in buried lacustrine sediments of the Coachella Valley, suggesting at least seven iterations of the Holocene Lake Cahuilla with the usual mixing pattern and biota. Many Desert Cahuilla artifacts are associated with Holocene Lake Cahuilla shorelines and recessional terraces in the northern Salton Trough, such as fishing camps, fire pits, pottery and pottery shards, bedrock morteros, rock shelters, charred bones of freshwater fish of the Colorado River system then inhabiting Lake Cahuilla, and personal adornments, found both along the Lake Cahuilla still-stand elevation of ~10 m above sea level and on recessional terraces down to at least −33 m (Bean and Saubel 1972; Balch and Balch 1974; Karr 1985; Bean et al. 1991; Gobalet 1992, 1994; Schaefer 1998; J. von Werlhof 2001, pers. comm.; Oglesby pers. obs.).

Two major styles of Indian stone structures in the Salton Trough have been called "fish traps." One type is easily seen at the west end of Avenue 66 at Jefferson Street—a display of some 650 pits, first described over 100 years ago (Bowers 1891; Rust 1891; Gates 1909; Strong 1929; Kniffen 1932; Treganza 1945; Balch and Balch 1974; US Department of the Interior and The Resources Agency of California 1974a,b; Wilke 1980; Karr 1985; Bean et al. 1991; Schoenherr 1993a; Dozier 1998; deBuys 1999; Pepper 1999; Cornett 2000; Lindsay 2001; Oglesby pers. obs.). These pits are roughly circular depressions, some with built-up walls, <1 to 2 m deep by 1 to 4 m across, arranged linearly and close together along 15 successive recessional shoreline terraces. The terraces are ~2 m apart in elevation on a steep talus slope composed of large (0.3 to 0.7 m) rounded boulders, corresponding to falling lake elevations in 15 successive years of maximum Lake Cahuilla desiccation rates. Similar pits occur on talus slopes elsewhere below the still-stand shoreline of Lake Cahuilla along the base of the Santa Rosa Mountains (Bean et al. 1991; Schaefer 1998; Lindsay 2001; G. Ridgeway pers. comm.). Pits may have originally had two separate openings on the

downslope side, each ~0.6 m wide. Because of the yearly ~2 m desiccation of the lake when deprived of Colorado River inflow, each row of depressions could be used only one season while at the water's edge.

Despite the popular name, the actual function of these pits is not known. Most people assume that the name "fish traps" is correct, and so argue about *how* they might have been used for fishing, rather than questioning *whether* they were used for fishing at all or what other possible uses might have been (G. Ridgeway, pers. comm.). Schaefer (1998) quoted extensively from early reports (Bowers 1891; Rust 1891; Gates 1909) which recounted Cahuilla oral traditions that these pits were used in conjunction with tides to catch fish; several writers believed Lake Cahuilla was connected to the ocean in the Gulf, at least at high tide. But Lake Cahuilla was never connected to the ocean at sea level—its still-stand elevation was ~10 m above sea level. When desiccating, Lake Cahuilla was a terminal lake in a closed basin. No inland body of water in the world, however large, displays lunar tides (see below). These reported Cahuilla oral accounts involving tides were seriously in error, a fact which casts some doubt on the validity of other aspects of contemporary Cahuilla accounts of their pre-contact cultural practices. Various recent writers have proposed diverse other pit fishing methods, some clearly impossible, including weir fishing (impossible on such steep slopes, since there would be no shallow substrate support for the "wings"), trapping fish that entered the depressions to feed or spawn by blocking the downslope openings with boulders or other objects, frightening fish to seek shelter in the pits, luring fish into the pits by night-lighting with torches, baiting, inserting nets within the depressions, or catching floating dead fish in some unstated way; poisons were apparently not used (Strong 1929; Treganza 1945; Bean 1972; Wilke 1976a, 1980; Bean et al. 1991; Dozier 1998; Schaefer 1998. Pepper 1999; Cornett 2000; Lindsay 2001). Treganza (1945) suggested that these pits were not used for fishing, but Wilke and Lawton (1975), Schaefer (1998, pers. comm.), and J. von Werlhof (pers. comm.) called his arguments "flawed" and dismissed his interpretations. Wilke (1976a, 1980) wrote that usage of the pits as traps would have stopped when the salinity of desiccating Lake Cahuilla became too high for freshwater fish, but the lake's elevation would have had to drop much lower than the lowest pit "fish trap" elevation (~33 m below ocean sea level) before becoming too saline for freshwater fish.

A much different type of "fish trap" is found on the more gently sloping bajadas below the steep slopes of the southern Santa Rosa Mountains, Fish Creek Mountains, and Superstition Mountain, as well as at the mouth of San Felipe Creek at the present Salton Sea and the Salton Sea Naval Test Base (J. Schaefer 1998, pers. comm.; Dower 2000; von Werlhof 2001; G. Hurd, pers. comm.). These non-circular fish traps are confined to broad recessional terraces of a desiccating Lake Cahuilla, some at the still-stand elevation (~+10 m), most from −13 to −46 m, and some lower than −60 m; several traps may occur on the same terrace. Each trap consists of a U- or V-shaped closed end made from available desert rocks about the size of bowling balls, each end connected to a long "wing" of stones, the two wings parallel or sub-parallel to each other with the downslope wing shorter than the upslope wing; these traps are linear, not circular, features. The highest elevation traps have the greatest structural diversity, the lowest elevation traps the least. These structures were built and used underwater; often tufa

connects several adjacent rocks and freshwater fossils (ostracods, snails) are found both in the tufa and in the soil under the rocks (G. Hurd, pers. comm.). Von Werlhof (2001) provided dimensions in his Table 1. Lengths of the two arms may have varied from ~0.3 to ~4.5 m, with the longer arm being ~2.5 times as long as that of the shorter. Such structures would be appropriate for weir fishing, given the gentle slope and the two wings. Once fish were herded into the closed end of a trap, it would have been easy to block the small opening with stones or baskets and then to harvest the fish. Fish traps on any single terrace could have been used only one season as Lake Cahuilla desiccated. Well over 450 weir fish traps have been documented since ~1940, but many have since been lost to development and highway construction.

A major question concerns the date of the last desiccation of Lake Cahuilla. Early Spanish explorers made no mention of a large lake in the Salton Trough (Sykes 1914; Vedder et al. 1993). The first European to enter the Salton Trough was perhaps Hernándo de Alarcón in 1540, a member of Francisco Vásquez de Coronado's expedition out of Sonora, México, to find the fabled Seven Golden Cities of Cíbola. Sailing north along the eastern shore of the Gulf, Alarcón was the first European to "find" the Colorado River; he traveled upstream by boat and interacted with local Quechans. Melchior Díaz's 1540 land expedition also explored the lower Colorado River while looking for both Alarcón and Coronado. In 1605 Juan de Oñate, the first governor of New Mexico, found the Colorado River flowing and explored it from its mouth in the Gulf north to the Gila River, as did Padre Eusebio Kino, for 24 yr Arizona's beloved "padre on horseback," in 1700. The 95 yr between Oñate's and Kino's observations is the longest single time period since 1540 during which a Lake Cahuilla might have been present, a time span too short to accommodate a complete filling to the still-stand elevation and then desiccation (Winspear and Pye 1995).

Had any of these early explorers from 1540 on entered the Salton Trough, they would have encountered Lake Cahuilla had it been in existence; surely they would have investigated such a huge lake. Furthermore, if there was a Lake Cahuilla in the Salton Trough at that time, the Colorado River would not have been flowing to the Gulf except by way of the Río Hardy, well west of the main channels explored by the Spanish (Wilke, 1976a; Schaefer 1998). Wilke (1976a) and Schaefer (1998) concluded that 20th century Cahuilla accounts of Lake Cahuilla desiccating, rapidly refilling—causing residents to flee for their lives—and then desiccating again in the 1600s or 1700s "represented a mythic catastrophism evoked from oral traditions . . . and not historical events." Schaefer (1998) qualified this conclusion by arguing that recent recognition that many Indian fish camp artifacts and fish traps from 0 m down to −60 m date, in radio-carbon years, to the 95 yr period from 1605 to 1700, when no Spanish explorers were in the region, "provid[e] compelling evidence of a late refilling, perhaps [only] a partial one." Archeologists, anthropologists, ethnographers, geologists, and paleontologists still differ on the date of the final desiccation of Lake Cahuilla, some preferring a date as recent as 1750 (e.g. J. von Werlhof 2001, pers. comm.), while others espouse a date several centuries earlier (e.g., Blake 1857, 1914). They also differ strongly on how many different iterations of Lake Cahuilla occurred in the Holocene.

The first Juan Bautista Agustín de Anza expedition of 1774 is generally credited as being the first real European contact with the Salton Trough and its several

native groups, and was certainly the first to cross the Colorado Desert in the Salton Trough. Anza's first expedition opened the first inland route to the California coast, which the Spanish had begun to colonize only as recently as 1769 at San Diego; 1769 is generally recognized as the start of the Historic Period in California (Chartkoff and Chartkoff 1984). Anza crossed the southern Salton Sink (impossible had Lake Cahuilla been present) and left by way of Coyote Canyon in what is now Anza-Borrego State Park. With him were Padres Francisco Gárces and Juan Díaz, and the Indian guide Sebastián Tarabal, a runaway from Misión San Gabriel Arcángel. Anza camped near the always reliable water at San Sebastian Marsh on San Felipe Creek, which he named for Sebastián Tarabal. Anza learned that two years earlier (October 1772), Lt. Pedro Fages and three Spanish soldiers had entered the Trough from the west while searching for deserters from the Presidio in San Diego; Fages camped as far east as San Sebastian Marsh, and his visit was well remembered by local Kumeyaay (Lindsay 2001).

Several times in the last 200 yr the Colorado River temporarily abandoned its normal southward course to the Gulf to flow into the Salton Trough, usually through the New River channel, which heads at Laguna Volcánica but sometimes through the Alamo River channel. (Fig. 4; Sykes 1914). Overflows are known to have occurred in 1840, 1842, 1849 (when the New River was named, though not when it was created), 1850, 1852, 1853, 1859, 1862, 1867, 1891, and 1899, some creating small lakes in the Salton Sink playa (Blake 1914; Sykes 1914; Oertle 1964; Nordland 1978).

The published dimensions of the 1891 lake (called Salton Lake) are approximately 16 km by 48 km, somewhat smaller than the present Salton Sea and around 1.8 m deep (Oertle 1964 Nordland 1978, and Cohen et al. 1999). The 1891 lake had to be much smaller and shallower than the present Salton Sea since it lasted only ~2 yr.

Before the formation of the Salton Sea in 1905, the Salton Sink playa was covered with a thick layer of salt (NaCl) which overlay a ~7 m layer of wet, black ooze. This wet layer was sometimes thought to represent seepage of ocean seawater from the Gulf of California through the deltaic dam, but this is not the case (Dowd 1960). Like Badwater in Death Valley well to the north, saline groundwater coming from the New River and other local sources (de Stanley 1976) rose close to the surface in the playa. Johnston (1987) quoted a mid-19th century traveler who was appalled to see the Salton Sink in full moonlight, "the ghastly pallor of death . . . a great plain of snowy salt." In 1892 the Salton Sink was described as a salt marsh (Blake 1914), but it was really a desert playa with a surface of evaporite sodium chloride (NaCl) deposits, long used by the Desert Cahuilla and Kumeyaay (Blake 1914; Laflin 1995, 1998), probably with alkaline or salt marshes near areas of permanent seep water. In 1815 Spanish colonists on the coast finally listened to the Indians and instead of importing salt from México began to mine it from the Salton Sink, carrying it to Los Angeles every spring, in an arduous trek using Coyote Canyon. In the 1830s, the Spanish switched to exploiting NaCl concentrated from evaporation ponds at Redondo Beach on the seacoast, much closer to Los Angeles (Johnston 1987; Laflin 1995, 1998). Salt ("excellent quality") was again mined from the Salton Sink beginning in 1884 by the New Liverpool Salt Company, continuing until the salt works were permanently flooded out in 1905; New Liverpool was also flooded by 1891's smaller

lake (Cory 1913, 1915). A railroad siding and a small support community were named Salton for the Company. New Liverpool's salt works and the community of Salton were inundated by as much as 20 m of water by 1907. Nordland (1978) and Laflin (1995) wrote that suits for damages were unsuccessful, but Dowd (1956) wrote that the New Liverpool won "excessive" damages ($458,246.23) against the California Development Company, a judgment ultimately upheld by the US Supreme Court.

Formation of the Salton Sea and its Recent History

Many popular, semi-scientific, and even scientific discussions of the Salton Sea perpetuate a number of errors about its formation, early days, and present condition. Wambaugh (1992) in *Fugitive Nights* provided a précis of common errors mixed with a few facts: "The Salton Sea was a mistake of man and perhaps of nature. Just after the turn of the century, some railroad builders made a horrible error with the Colorado River, and a levee burst, allowing millions of cubic feet of water per day to rage into a high salt marsh left over from an ancient inland sea. The Salton Sea submerged everything under water fifty percent saltier than the ocean. It was said that pumice rock could float in this saltiest of water, 235 feet below sea level." The real origin of the Salton Sea is strange enough without such embellishments.

Right from its remarkable beginnings in 1905 to 1907, the Salton Sea has been much written about (Byers 1907; Davis 1907; James 1907; Rockwood 1909, 1918; Howe and Hall 1910; Cory 1913, 1915; Sykes 1914; Kennan 1917; Farr 1918; Tout 1931; Woodbury 1941; Burns 1952; Dowd 1956; Carpelan 1961a; Elders 1979b; Fradkin 1981; de Stanley 1976; Laflin 1995, 1998; and deBuys 1999). Early accounts were often promotional pieces about the Imperial Valley, either explaining away the two-year flood or just ignoring it. Kennan's (1917) little book is typical of this approach, despite good maps.

Other early books were written by active participants. Rockwood's (1909) account is defensive and partisan. He was head of the California Development Company which dug the inadequate Mexican Cut (whose expectable breach by the Colorado River had created the Salton Sea). Rockwood had been severely criticized for "gross negligence and criminal carelessness" ("but how could one foresee that which had never happened before?"); he was more responding to his critics than writing a chronological history. Tout (1931) reprinted Rockwood's (1909) apologia, but wrote little on the breach, flood, or repair. Woodbury's (1941) enjoyable account is detailed and accurate, but couched in a strange setting of fictional surrogate characters and imagined dialog.

The best early account, with excellent maps and diagrams, is by Harry T. Cory (1913, 1915), the Southern Pacific Railroad engineer who managed the final, successful attempts to close the Colorado River's levee breach. Though Cory covered only the later portion of these events, his account is detailed and accurate. In addition, the paper by Cory (1913, reprinted in Cory 1915), provided an evaluative and valuable discussion of his paper by water engineers. One of these, Andrew Chaffey (son of George Chaffey, Jr., who was for a while, prior to construction of the Mexican Cut, the chief engineer for the California Development Company) praised Cory's paper as "the first serious history of the Imperial Valley" and called it "fair and unprejudiced." By contrast, Chaffey was scathing in

his criticisms of Rockwood (1909) and Howe and Hall (1910), using such words as, "rambling sketches," "unsystematic," "partisan and misleading statements," and "untrustworthy and unsatisfactory." By contrast, Howe and Hall (1910) described Rockwood as a man "of largest possible vision."

Modern accounts of the events of 1905 to 1907 often contain errors about dates, facts, and incorrect assignment of responsibility (e.g., see the quote by Wambaugh [1992], above). The best and most complete modern accounts are Burns (1952), de Stanley (1976), Laflin (1995, 1998), and deBuys (1999); even so, they cannot be relied upon for their discussions of the geology and biology of the Salton Sea. Many popular and semi-scientific articles stimulated by proposals by the Salton Sea Authority to "save" or "restore" the Salton Sea are both superficial and error prone.

Proposals to bring Colorado River water by gravity to irrigate the Salton Trough were put forward as soon as Blake recognized in 1853 that the basin was below sea level. In 1857, Dr. Oliver Meredith Wozencraft, forty-niner, physician, federal Indian Agent for southern California, and visionary, persuaded the fledgling California legislature to pass a bill to encourage bringing Colorado River water to irrigate what is now the Imperial Valley. All it would take, Wozencraft said, would be money, since Colorado River water could be delivered by gravity alone. He spent nearly four decades unsuccessfully trying to convince the US Congress to finance irrigation projects for agriculture in the Trough; he died before his proposal was considered by Congress. Wozencraft is often called the "Father of the Imperial Valley" (Lindsay 2001). In 1873, Dr. Joseph P. Widney, in *Overland Monthly,* proposed diverting the entire Colorado River into the Salton Trough, recreating Lake Cahuilla. The plan ("Lake Widney") was opposed by Congress, most of whose members thought that the Salton Trough was better suited for agriculture than for a very large lake (Laflin 1995, 1998; Lindsay 2001).

Blake (1854, 1914) wrote: "It becomes evident that the alluvial soil of the Desert is capable of sustaining a vigorous vegetation. The only apparent reason for its sterility is the absence of water. By deepening the channel of the New River, or cutting a canal so low that the water of Colorado would enter at all seasons of the year, a constant supply could be furnished to the interior portion of the Desert. With work it is probable that the greater part of the Desert could be made to yield crops of almost any kind." Prophetically, Blake also warned in his initial report of 1854: "It is indeed a serious question, whether a canal would not cause the overflow once more of a vast surface, and refill, to a certain extent, the dry valley of the Ancient Lake."

Water engineer and developer Charles R. Rockwood organized the California Irrigation Company in 1891 to carry water from the Colorado River to the Salton Trough, but the company failed in the panic of 1893. Agricultural development in the Imperial Valley began in earnest in 1901 when the California Development Company, reorganized in 1896 by Rockwood and water engineer and developer George Chaffey, Jr., opened the Alamo Canal (also called the Imperial Canal) (Fig. 4). Chaffey grandly renamed the desert south of the Salton Sink the Imperial Valley. Rockwood's Alamo Canal brought water to the Imperial Valley by gravity from the Colorado River, roughly following one of the drainages (the then-dry Alamo River) that the Colorado would take when it naturally shifted its course into the Salton Trough. James (1907) and deBuys (1999) described in detail the

rapid development of agriculture in the Imperial Valley once water was first delivered in 1901, including the establishment of eight town sites. Chaffey resigned from the California Development Company in 1902 "before its collapse, [but] his reputation suffered from this brief alliance" (Kahrl 1982). Chaffey was replaced by Anthony Heber, who worked with Rockwood to make as much money as possible through the California Development Company. Their actions were characterized by "bungling, negligence, and greed" (deBuys 1999), although other writers have been more charitable (e.g., Laflin 1995, 1998).

With cheap water made abundantly available by gravity and intense publicity throughout the US, often with much hyperbole, about the fertile soil and year-long growing season, the population of the Imperial Valley quickly rose to >10,000 by 1904 and ~15,000 by 1909 (cultivating 40,000 hectares [ha]), but did not rise much higher than 40,000 until after World War II. The population of the Valley is now ~100,000, cultivating somewhat over 100,000 ha. In February 1995, at a surface elevation of −67 m, the Salton Sea was 56 km long, 14 to 24 km wide, and 930 km^2 in area, with a total shoreline of 153 km, maximum depth ~16 m (in both basins), average depth 5 m, and a total capacity of 9,420,566 acre-feet (Ferrari and Weghorst 1997). (An acre-foot is the volume required to cover an acre to the depth of one foot.) (Note: 1 million acre-feet = 1.233 cubic kilometers [km^3]. Since the acre-foot is the unit used by all US water and agricultural agencies, and since there is no convenient metric equivalent, acre-feet will be used throughout this article.)

The original 1901 headgate of the Alamo Canal (Chaffey Gate at Hanlon's Landing: Woodbury 1941) was on US soil in California at Pilot Knob, just downstream from Yuma, at an elevation of ~32 m above ocean sea level and 120 m above the deepest part of the Salton Sink (Fig. 4). To avoid the Algodones Dunes, the Alamo Canal (called the Imperial Canal in Fig. 4) initially ran for ~65 km through México just south of the California border until it nearly reached Laguna Volcánica. At that point (Sharp's Landing, with a concrete headgate smaller than Chaffey's at Hanlon Landing: Woodbury 1941; Dowd 1956), irrigation water was turned north to flow to the Imperial Valley. The price for this international concession was that México's Valle de Mexicali was to get half the water diverted by the Alamo Canal. Rockwood also had to set up a subsidiary company chartered in México, La Sociedad de Irrigación y Terrenos de la Baja California. In 1902 the Southern Pacific Railroad built connecting lines from its main transcontinental track (completed from Los Angeles to Yuma in 1877 via San Gorgonio Pass and the Salton Trough, the last link in its transcontinental railroad) into the Imperial Valley for shipment of crops (Fig. 4). The first crops, chiefly wheat and barley from ~6200 ha, were harvested in 1903. But the low flow gradient at the Alamo Canal intake at Hanlon's Landing in California, created partly because Chaffey did not make the headgates high enough, coupled with the always silty Colorado River, meant that the intake system regularly silted up. Simple bypasses were constructed nearby for the low water flow winters of 1902–1903, and 1903–1904, using brush mats held down by wire as expedient headgates (not shown in Fig. 4; see Cory [1913, 1915]). These bypasses were expected to be inadequate for the winter of 1904–1905 (Dowd 1956). Farmers complained.

In October 1904, after a long period of canal siltation and non-delivery of irrigation water, the California Development Company hurriedly opened a "cheap

wooden headgate" (Davis 1907) downstream from the initial one, 6.4 km south of the Mexican border where there was a greater slope—the "Mexican Cut" (Fig. 4). James (1907) described this new headgate as "a temporary expedient," and wrote that Rockwood took "desperate chances" in relocating the canal's headgate downstream in México. Rockwood (1909) explicitly wrote that the Mexican Cut location was *not* selected because the gradient was better there, but because the water capacity was greater there. Rockwood (1909; quoted with apparent agreement by Cory [1913, 1915]) stated that he thought the Mexican Cut would be only a temporary measure, and the breach in the Colorado River could be closed within six months, before the usual summer floods in 1905; he would also not have to seek Mexican permission. Cory (1913, 1915) stated clearly that the Mexican Cut headgate was not concrete or wood, but rather like the several bypasses around Chaffey Gate at Hanlon's Landing, that is, brush bundles held down by wire. Cory (1913, 1915) bluntly stated that, "making this cut was a blunder so serious as to be practically criminal." George Chaffey was also opposed to the Mexican Cut, saying that the Imperial Valley's problem was not real lack of water, but siltation (Tout 1931).

The Mexican Cut was not adequate to handle even an ordinary flood. As it turned out, the decade from 1900 to 1910 was one of the wettest on record, and was on the crest of a several centuries high in rainfall and river flow, as documented by a millennium of tree-ring weather records. Rockwood was quoted by Laflin (1995) as being worried about the consequences of not getting permission from the Mexican government to relocate the headgate into Mexican territory. He soon got approval by telegram from México's Presidente Porfirio Díaz in 1904, but did not get formal approval until more than a year later (Woodbury 1941). During the winter low-water season of 1904–1905 Imperial Valley farmers received adequate water.

The Colorado River rises in the Rocky Mountains of Wyoming and Colorado at 3500 to 4000 m. It is fed by highly seasonal and annually variable snowmelt and rainfall, and drops steeply to sea level in only 2720 km (Fradkin 1981). The virgin Colorado River always flooded each year in late spring through early summer, some years much more severely than others; late spring and summer flood flows from Rocky Mountain snowmelt varied by a factor of over 100 times, from a low of 622 cubic meters per second ($m^3\ s^{-1}$) to a high on 22 January 1916 of 88,288 $m^3\ s^{-1}$. The River frequently flooded in excess of 28,316 $m^3\ s^{-1}$ (deBuys 1999). In addition, there were often late winter and early spring floods from heavy rains at lower elevations. By late summer and autumn each year, the undammed Colorado became a much smaller, calmer, silty, lukewarm river which posed no flood danger. In spite of the absence of proper headgates, no one watched the Mexican Cut for any signs of trouble during spring 1905 (Cory 1913, 1915). In winter and spring 1905, there were five major floods on the Colorado River, one of which was the second largest recorded in Euro-American historic times (Kahrl 1978), further augmented by floods on the Gila River in southern Arizona. By early spring 1905, the flooding Colorado River had easily breached the Mexican Cut and began to flow into the Salton Trough by way of Laguna Volcánica and the New and Alamo Rivers (Fig. 4). By the end of August 1905, the entire volume of the Colorado River was flowing westerly and then northerly into the Salton Trough instead of southerly to the Gulf of California. The flow was chiefly via

the New River, erasing several small lakes and lagoons (Cameron Lake, Blue Lake [at 70 ha the largest of these], Calf Hole, Pelican Lake) along the river near the Mexican border, lakes that had provided water for local Indians, travelers, and livestock and which were good wildlife habitat. Broad sheets of flood waters washed out bridges.

The newly forming lake in the Salton Sink, immediately named the Salton Sea, rose rapidly (by as much as 17.5 centimeters per day [cm d^{-1}]: Sykes 1937), and submerged the New Liverpool salt works as well as roads and other buildings adjacent to the playa. Major Colorado River floods again occurred in winter and early spring 1906, washing out almost-completed repair works several times. James (1907) provided much detail, including informative maps, on early efforts to force the Colorado River back into its original bed. When he had completed his manuscript in October 1906, James thought that the Mexican Cut breach would be closed within the month. Despite serious damage again to the almost-finished repair works by a November 1906 flood, James' (1907) prediction was ultimately correct, if postponed. By early spring 1907 the breach was permanently repaired in the seventh attempt, and the entire Colorado River again flowed south to the Gulf (Cory 1913, 1915). deBuys (1999) called this two year flood into the Salton Sink the "Great Diversion," a term that no one else has used. In August 1907, residents of the Imperial Valley voted overwhelmingly to secede from San Diego County, which had always ignored what was going on so far east and continued to do so during the flood, forming Imperial County (Howe and Hall 1910).

Many current accounts, popular and scientific, call the 1905 to 1907 formation of the Salton Sea an "accident." Typical is Skrove (1986) writing for the Metropolitan Water District; the title of his article is "Salton Sea: Nature's mistake in the desert." He called the Salton Sea "a freak of nature," and described its origin: "A tempestuous Colorado turned inland and gushed down a system of canals and conscripted riverbeds." But writing as early as 1906, James (1907) called the Mexican Cut and several subsequent engineering decisions a "fatal mistake." Davis (1907) stated bluntly, "the irrigating company [was] responsible for the break." A 1960s letter written by a Wiley Magruder (quoted by Laflin 1995) said, "The Salton Sea lies there a shining shimmering monument to man's carelessness." de Stanley (1976) wrote, "The Salton Sea was born of man's mistake." Pepper (1999) wrote of "careless construction." The California Water Atlas (Kahrl 1978) called the Sea's formation an "engineering mistake." Fradkin (1981) concluded that this human-caused breach was "no accident," based as it was on inferior construction of irrigation works; rather, it was "one of the greatest engineering mistakes of the century." Kaiser (1999) was even stronger, calling the formation of the Salton Sea an "engineering debacle."

The 1905 to 1907 Colorado River floods created a waterfall (called the Cutback) in the New River that, because of soft, highly erodable lacustrine sediments, retreated rapidly upstream (southerly) from the rising Salton Sea, a problem predicted as early as 1853 by Blake (Blake 1854, 1914). A similar but less publicized cutback developed in the Alamo River. Harold Bell Wright in his best-seller 1911 romance, *The Winning of Barbara Worth,* correctly wrote about the New River waterfall: "The imminent danger that threatened the [Imperial] Valley was not the danger from the ever-rising sea. Long before the waters could fill the old sea-

bed [*sic*], that mighty cataract, moving ever upstream, would pass the intake; and with the floor of the river lowered some [16 m] it would be impossible to take the water out for irrigation. The lands reclaimed by the pioneers would go back to desert years before they would be buried once more under the surface of the sea." Wright's (1911) novel fictionalized the "reclamation" of desert lands to agricultural lands, lightly disguised the Imperial Valley, turned promoter Rockwood into a hero ("The Seer"), and ended with a simplified formation of the Salton Sea as the backdrop to plot resolution; the novel is better literature than history. Wright occasionally used one of the older names for the Salton Trough, the lovely La Palma del Mano de Díos (The Palm of God's Hand).

The 1905 to 1907 cutback in the New River retreated upstream as much as 1 kilometer per day (km d^{-1}), becoming progressively higher as it cut south; it reached Calexico in early 1906. The Alamo River cutback passed Holtville at the same time (Davis 1907; Elders 1979b). There was great concern that if the cutback reached the Colorado River bed itself, it would take out Laguna Dam (Fig. 5; called Laguna Weir by Cory 1913, 1915), then being constructed a few km upstream from Yuma by the newly established US Reclamation Service to irrigate the Yuma Valley (Davis 1907; Cory 1913, 1915). Rockwood (1909) complained that the US Reclamation Service "retarded and handicapped" the California Development Company in dealing with the flood. The cutback was curtailed in Laguna Volcánica in México, by dynamiting. Four-fifths of Mexicali was washed away, and other communities in the Imperial and Coachella Valleys were flooded.

Rockwood's California Development Company, always under-capitalized, immediately went into receivership. The Southern Pacific Railroad first loaned money to the company and then loaned its engineers, and began attempts to save its own transcontinental railroad and Imperial Valley spurs, several times moving 96 km of its tracks uphill (the last time to the −61 m contour, where they remain) and eastwards as the Salton Sea rose (Blake 1914; Sykes 1914; Cory 1913, 1915; Laflin 1995, 1998; deBuys 1999). Southern Pacific quickly became entangled in the financial and engineering affairs of the California Development Company.

The 18 April 1906 M 7.8 earthquake and fire in San Francisco delayed repair of the Colorado River breach, as state and national attention and potential money for disaster relief were focused on San Francisco. Southern Pacific suffered great damage in the quake, and its new dredge *Delta,* being built in Oakland, was also severely damaged and therefore much delayed in arriving at the Colorado River. Nevertheless, the *Delta* proved extremely important in the success of the seventh and last attempt to close the levee breach (Cory 1913, 1915).

By heroic efforts of men associated with the Southern Pacific Railroad headed by Cory, greatly assisted by Indians of the Imperial Valley, lower Colorado River, and northern Baja California recruited by Cory, the Colorado River was finally forced back into its normal southwards channel in February 1907. Work was complicated by the presence of a large sand bar covered with cottonwoods (*Populus fremontii*) and arrow weed (*Pluchea sericea*), dubbed Disaster Island, in the middle of the river directly across from the Mexican Cut (not shown in Fig. 4; see Cory [1913, 1915]). Disaster Island diverted water and flood debris directly into the Mexican Cut, enlarging it and destroying repair work. Ultimate success came only by dumping immense boulders from specially-built train cars on a trestle built on pilings across the levée break. The Mexican Cut breach in the

Colorado River had widened in 2 yr from its initial 17 m to 1.2 km. All available rolling stock west of the Mississippi was mobilized by Southern Pacific and Union Pacific, spending >$5 million on a repayment promise from President Roosevelt to Southern Pacific President Harriman (who also controlled Union Pacific). de Stanley (1976) and Laflin (1995) presented a fascinating December 1906 to January 1907 telegram exchange between Harriman and Roosevelt, who initially believed that the railroad was directly responsible for the flood. Harriman persuaded the President that only the California Development Company was responsible, which deBuys (1999) regarded as debatable given the close control of the development company by the railroad. President Roosevelt promised federal financial assistance. de Stanley (1976) published the entire text of the President's January 1907 message to Congress, making a strong case for federal involvement and financing. Imperial Valley Rep. Smith opposed the bill because of its proposed transfer of all irrigation works to the new federal Reclamation Service, and the bill failed. Southern Pacific was repaid by the US government only in 1930 and then only $1,012,665.17 (de Stanley 1976; Elders 1979b).

The present New River near Calipatria shows the conspicuous 1905 to 1907 river bed, now dry and here ~0.8 km wide and 10 m deep, cut in only 2 yr; further upstream (south) it is incised as much as 16 m. The post-1907 New River here has cut a much narrower inner channel, ~10 m deep, which meanders across the wide 1905 to 1907 bed (Oglesby pers. obs.). Cory (1913, 1915) pointed out that an important benefit of the 2-yr flood was that the creation of *barrancas* (deep gorges) in the New and Alamo Rivers made them much more effective as agricultural wastewater drains than their shallow pre-flood states when waste water frequently flooded adjacent lands.

Construction and careful maintenance of levées along the Colorado River averted a re-establishment of the breach during the spring and summer floods of 1907. Within a few years additional levees were built along the distributaries leading to Laguna Volcánica, averting floods from that direction (Cory 1913, 1915). In 1909 the US Reclamation Service (renamed the US Bureau of Reclamation in 1924) finished Laguna Dam just north of Yuma and relocated the headgates of the Imperial Canal to above that dam. The original Alamo Canal now diverts water from behind México's Morales Dam, the final dam on the River (Fig. 5) into the Valle de Mexicali.

The powerful Imperial Irrigation District, the largest irrigation district in the US, was organized in 1911 and has prior appropriation rights over all other water agencies in California for water from the Colorado River; it is, in fact, the largest single user of Colorado River water in any state. The District bought the remaining assets of the California Development Company from the Southern Pacific Railroad and distribution canals from several mutual water companies (US Department of the Interior and The Resources Agency of California 1969). The Boulder Canyon Act of 1928 authorized not only Hoover Dam in the Black Canyon of the Colorado, but also a new All-American Canal heading from above Imperial Dam. When the new canal was completed in 1939 (Fig. 5), the District finally had a canal whose permanent headgates would assure its allotted share of Colorado River water. Not until Hoover Dam was completed in 1936 were the problems of Colorado River floods, siltation, and levée maintenance overcome (Laflin 1995, 1998; deBuys 1999). From the beginning at the turn of the century,

the *Los Angeles Times* was a major booster of these irrigation projects. Perhaps not coincidentally, Harrison Gray Otis, publisher of the *Times,* was the leader of a syndicate of southern Californian businessmen that owned most of the Valle de Mexicali under the name Colorado River Development Company, incorporated in México (Cory 1913, 1915).

The Imperial Irrigation District now serves 113,671 ha of irrigated lands, involving 6000 headgates and 4800 km of canals, all ultimately draining to the Salton Sea (Fradkin 1981; Breuer 1992). "The Imperial Valley boasts one of the most complex hydraulic engineering projects in the world" (Cohen et al. 1999). The Coachella Canal, a northern branch of the All-American Canal, and its canal and drain system were completed in 1949 (Fig. 5; US Department of the Interior and The Resources Agency of California 1969; Nordland 1978; Fradkin 1981). The Coachella Valley Water District serves 16,447 ha in the Coachella Valley, where irrigated agriculture began in 1884, using both groundwater and Colorado River water (Nordland 1978). The Imperial Valley uses 86% of the Colorado River water initially diverted into the All-American Canal, and the Coachella Valley the rest. A brief but detailed chronology of Colorado River dams and diversions, state and federal legislation, major legal and political actions, and unresolved issues is provided by Newman (1998).

With 9 major dams and reservoirs on its mainstem and at least 14 additional dams on its tributaries, the Colorado River no longer carries much silt and no longer floods, except when excess water releases are made from upstream dams, as happened in 1983 with releases from Glen Canyon Dam to prevent it destroying its spillway (Weatherford and Brown 1986b; Reisner 1993). Because of its many reservoirs, the Colorado River has been changed from a lukewarm- to a cold-water river. Its suite of extraordinary native fishes (37 species, 23 of which were endemic), marvelously adapted to surviving raging spring floods and low, warm late summer flows, is effectively extinct in the tamed Colorado River itself. Three species are now extinct, and 17 additional species are listed as federally Threatened or Endangered, most hanging on only in the few undammed upstream tributaries (Colorado River Wildlife Council 1977; Holden 1979; Nicola 1979; Hamman et al. 1994; Rinner and Tyus 1994). Two of these Endangered species are no longer found in the California reach of the Colorado River: the Colorado squawfish (*Ptychocheilus lucius,* now officially called Colorado pikeminnow), a predatory minnow that could exceed 36 kg and 2 m, and the bonytail chub (*Gila elegans*), which was found in the newly formed Salton Sea until its rising salinity eliminated the chubs by the second decade of the 20th century. Only one of the Colorado River endemic species is now found in the Salton Trough, the humpback or razorback sucker (*Xyrauchen texanus*). It is on both Federal and California Lists of Endangered Species, and is occasionally seen in drains and canals (Table VIII; Imperial Irrigation District 1994).

The popular idea that the Salton Sea was immediately saline in 1907 (Wambaugh 1992) is not true; the salt deposits in the Salton Sink playa came from freshwater lakes and were inadequate to raise significantly the salinity of two years of Colorado River floodwaters, a fact well known nearly a century ago (James 1907; Free 1914; Arnal 1961; Carpelan 1961b). Arnal (1961) stated that silt carried in the overflowing 1905 to 1907 Colorado River buried Salton Sink evaporite deposits so fast that they were not fully dissolved into the newly forming

Salton Sea. The Colorado River in 1907 had a salinity of 0.7 g l^{-1} and the initial Salton Sea was 3.6 g l^{-1}, a value reflecting both Colorado River salt input (20%) and salt leached from the playa (80%) (Table I; Arnal 1961; Carpelan 1961b).

In spring 1907 the new freshwater Salton Sea at its largest extent had a maximum area of 1583 km^2, almost twice that of the present Salton Sea; a maximum depth of 25.3 m, ~10 m deeper than in 2000; and a surface elevation of −59.4 m, nearly 10 m higher than in 2000. Scientists of the Desert Laboratory of the Carnegie Institute of Washington studied the biology, hydrography, and land forms of the desiccating Salton Sea for five years (1907 to 1912) and published a handsome report edited by MacDougal (1914a).

Cut off from the Colorado River in 1907, the Salton Sea at first desiccated by ~2 meters per year (m yr^{-1}), reaching its lowest elevation in 1925. It became a salt lake with a salinity of ~40 g l^{-1}, somewhat greater than that of ocean seawater. Initial opinion was that the Salton Sea would actually dry up, but with increasing inflow from increased irrigation wastewater, the Salton Sea in 1926 began to increase steadily and rapidly in volume, elevation, and area, and to decrease in salinity. President Coolidge in 1924 issued an Executive Order withdrawing lands below −80 m and in 1928 he further withdrew all lands below −72 m to provide "an evaporative pan for surplus and waste water from Imperial Valley irrigation development," with flooding rights controlled by the Imperial Irrigation District (Coachella Valley Water District 2000). These withdrawals were apparently done without the President's staff realizing that 3124 ha had already been withdrawn in 1876, 1891, and 1909 by the Department of Interior for the Torres-Martinez Desert Cahuilla Reservation, including 2340 ha that were soon inundated by the Salton Sea.

One major result of this error has been perpetual lawsuits, so far never successful for the Torres-Martinez Desert Cahuilla, even though the Imperial Irrigation District and the Coachella Valley Water District have settled many millions of dollars for inundation of agricultural lands and shoreline developments elsewhere around the Sea's shoreline, owned by non-Indians (James 1960; Lopez 1998; Pomento 1998; Cohen et al. 1999; deBuys 1999). In December 2000 Congress passed a bill that compensated the Torres-Martinez Desert Cahuilla $14 million ($10.2 million from the US, the rest from a settlement between the tribe and the Imperial Irrigation District and the Coachella Valley Water District).

Prior to the late 1990s, the highest salinity recorded for the Salton Sea was ~43 g l^{-1} in 1938 (Hely et al. 1966; US Department of the Interior and The Resources Agency of California 1969). The high salinity of the Salton Sea coupled with high evaporation rates and low rainfall associated with the desert climate led to several attempts at commercial salt production along the eastern shore during the 1930s and 1940s, more difficult than at the ocean because of the higher concentration of $CaSO_4$ (gypsum) (Table I). None of these operations was particularly successful, and all succumbed to rising waters by the mid 1940s.

In 1968, California enacted a statute declaring that the primary use of the Salton Sea was for collection of agricultural wastewater, seepage, leaching, and control waters (CA Stats. 1968, Ch. 392, Sec. Z).

In 1980, the US Supreme Court permanently exempted Imperial Valley farmers from two "onerous" provisions of the 1902 Reclamation Act: (1) subsidized federal water could be applied only to farms of 65 ha or less (130 ha for a married

couple), and (2) farmers had to live on or immediately adjacent to their lands. These provisions had been ignored in the Imperial Valley since the beginning of irrigated agriculture in 1901. In the 1990s 60% of the land ownership was absentee, and the largest single holding was 17,200 ha, ~10% of all the acreage in the Imperial Valley (Fradkin 1981; Hundley 1986; deBuys 1999).

Once the sport fishery was established so successfully in the 1950s (see below), there was a concerted attempt to turn the Salton Sea into a major destination resort, based on fishing, golfing, boating, relaxation, and the enjoyable climate (ignoring intense summer heat, windstorms, and sandstorms). The most ambitious of these residential resorts was Salton City on the western shore (Fig. 1), promoted as *the* paramount California resort, called the "Salton Riviera" (Lindsay 2001). It was "one of the Sea's liveliest resorts," with its golf course, motels, marinas, restaurants, boat-launching ramps, marine supply stores, trailer parks, a casino, and many lots for private residences; now it does not rate even a mention in the American Automobile Association's *Guidebook to the Southern California Desert Area* (Lindsay 2001). deBuys (1999) described how the promoter fleeced many hundreds of people; others believe that the developer was misguided and over-enthusiastic but fundamentally honest.

Burns (1952) and de Stanley (1976) rhapsodized about the shoreline resorts, but in fact none of them were ever remotely successful. All are ghosts now, with drowned marinas, yacht clubs, motels, and jetties; empty and vandalized motels and restaurants; closed casinos; and many of the few residences abandoned to sandblasting by the strong winds (see Landis 2000; Lindsay 2001; Oglesby pers. obs.). Empty and even developed lots have reverted to Imperial and Riverside Counties for unpaid property taxes, and real estate agents will not take listings since they know the properties will not sell. Snowbirds still winter in places such as Desert Shores and Bombay Beach, and the few die-hard permanent residents may be found anywhere.

Almost from its beginning in 1907, the Salton Sea was a focus of diverse recreation, including fishing (see below), birding (see below), waterfowl and dove hunting, camping, nature study, photography, sightseeing, ecotourism, boating, off-road vehicle use, rock and gem hunting, speed boat racing, sailboarding, water skiing, and jet skiing.

It is widely believed that the Sea's below sea level elevation and thus higher barometric pressure increases absolute concentration of oxygen (O_2) in the atmosphere, and that its high salinity creates greater water density and thus increased buoyancy, both factors making the Salton Sea the fastest body of water in the world for speedboat racing (e.g. Laflin 1998). Boat racing began as early as 1928. At the 1951 Regatta, 21 world records were set. Because airplanes could fly such a long distance below sea level in the Trough, a number of world speed records were set over the years (Laflin 1998).

Water contact recreation has declined in recent years (Salton Sea Authority and US Bureau of Reclamation 2000a), though the Sea has always been a Class I water, suitable for body contact. In the 1980s, the Salton Sea and adjacent wildlife areas had up to 1.5 million use-days per year (use-d yr^{-1}), more visitors than Yosemite National Park (Pomento 1998). Around 360,000 use-d yr^{-1} were for fishing and 1.1 million use-d yr^{-1} for other forms of recreation, involving yearly expenditures of well over $4 million. Visitor use gradually dropped to a low of

87,600 in 1994 to 1995, but has since rapidly increased to 275,000 in 1998 to 1999 (Salton Sea Authority and US Bureau of Reclamation 2000a). In an attempt to increase visitation, a $1 million fishing derby was scheduled for summer 2000 (*Los Angeles Times* 29 May 2000).

People have always complained about unpleasant odors emanating from the Salton Sea, particularly in the summer and usually attributed to sewage, which is most assuredly not the case (see below). Odors are at their worst in drowned agricultural fields nearly surrounded by former road dikes. This leads to poor circulation, and to summer mixing of hypoxic hypolimnic waters with surface waters, bringing hydrogen sulfide (H_2S) gas to the surface. These odors have been present for many decades, and do not seem to be getting worse at present, despite increasingly negative publicity (Oglesby pers. obs.). The Salton Sea Authority and US Bureau of Reclamation (2000a) attributed odors to the hypereutrophic condition of the Sea which leads to decaying organic matter and H_2S production, but eutrophication by itself does not necessarily cause odors. Another proposed source of odors is decaying fish from fish kills, attributed to recent problems in the Sea, though fish kills have been a regular occurrence since at least the 1950s (see below). Dead fish may rot while floating on the Sea, generating H_2S, but they desiccate quickly once they wash ashore, without generating any odors (B. W. Walker 1961; Oglesby pers. obs.).

Rumors and errors have surrounded the Salton Sea since its formation in 1907. Davis (1907) called published rumors that the newly formed Salton Sea was significantly altering the climate of the entire southwestern US "absurd." Henry (1907a) provided a longer analysis of the supposed climate problem and concluded that at most only a local and modest increase in relative humidity was likely. At various times books and articles in the popular press have publicized "imminent dangers," such as:

- Loss of Colorado River silt trapped behind Hoover and other dams would lead to tidal breaching of the Colorado delta and Gulf of California seawater flooding the Salton Trough.
- Strong earthquakes would open deep cracks in the delta through which Gulf seawater would flow, causing the Salton Sea to rise rapidly.
- The "mysterious and weird" Salton Sea was rising so rapidly from unstated water sources that it would soon burst its banks and flood the entire Salton Trough (nonsense on the face of it; there are no banks to breach as there are no lower adjacent areas to flood).

Imperial Irrigation District Executive Officer Dowd (1960) debunked all these purported "dangers," as did Oertle (1964). Dowd's pamphlet was self-serving to the District, but he was correct in his analyses of why these "dangers" were mere hyperbole and fears based on lack of scientific and historical knowledge.

Sources of Water to the Salton Sea

In 1995, at a surface elevation of -67 m, the Salton Sea was around 56 km long, 14 to 24 km wide, and 930 km^2 in area, with a total shoreline of 153 km, maximum depth ~16 m (in both basins), average depth 5 m, and a total capacity of 9,420,566 acre-feet (Ferrari and Weghorst 1997).

The Salton Sea receives almost all its water as wastewater from agriculture in

the Valle de Mexicali and Imperial Valley by way of the New and Alamo Rivers, virtually all deriving ultimately from the Colorado River (Arnal 1961; Hely et al. 1966; California Department of Water Resources 1970; US Department of the Interior and The Resources Agency of California 1974; Layton and Ermak 1976; Colorado River Board of California 1992; Salton Sea Authority and US Bureau of Reclamation 2000a). Inflow is ~1.3 million acre-feet per year (acre-feet yr^{-1}); the impounded volume in 1993 (surface elevation −69.5 m) was ~8 million acre-feet. Thus, ~16% of the volume of the Sea enters per year (Cook and Orlob 1997b). All these inputs are at least somewhat saline rather than pure freshwater, varying from ~2.5 g l^{-1} to 9 g l^{-1}, depending on evaporation rates and leaching of salts from fields. Listed in rank order, the individual water sources are:

1. Discharge of the Alamo River at its outlet to the Sea averages ~620,000 acre-feet yr^{-1} (46.1% of the total input to the Sea), of which only 0.3% enters the US from the Mexican side of the border. The Alamo River originates in México, crosses the US border some 11 km east of Calexico and Mexicali, and runs 84 km to its mouth at the southeast Salton Sea. The Alamo River (watershed 4344 km^2) is fed entirely by agricultural wastewater, but does not receive the heavy industrial and domestic pollution of the New River, and so has not been publicized as problematic (US Bureau of Reclamation 1998a; but see California State Water Resources Control Board 1981; Moore 2000).
2. The New River (Río Nuevo) discharges an average of ~438,000 acre-feet yr^{-1}, 32.5% of the total Salton Sea input, of which around one-third comes from México. The New River (watershed 6250 km^2) rises in México (originally at Laguna Volcánica), crosses the US border at Mexicali and Calexico, and runs 97 km to its mouth at the southernmost Salton Sea. The New River is widely regarded as the most polluted river in the US (Anonymous 1989, LFR 1999; *USA Today* 11 May 2000; Moore 2000), receiving pesticides and fertilizers from agricultural fields on both sides of the international border, organic inputs from cattle feed lots, industrial wastes both from Mexican industry and *maquiladoras* (foreign-owned Mexican export-assembly companies), and untreated sewage from Mexicali (population ~800,000 to 1,000,000), which lacks a viable sewage treatment system (*Time* Magazine 20 April 1987; Anonymous 1989; *Los Angeles Times* 4 November 1995, 7 August 2000; US Bureau of Reclamation 1998; *USA Today* 12 May 2000). Handsome color photos of New River debris are provided by Moore (2000). The New River deposits 5×10^8 kilograms per year (kg yr^{-1}) of suspended sediment onto its delta in the Salton Sea. Diverse projects have been proposed for cleaning up the New River (see below).
3. Surface drains from agricultural fields directly entering the Salton Sea are estimated to discharge ~106,000 acre-feet yr^{-1}, 7.9% of the total input.
4. The Whitewater River draining the San Bernardino and San Jacinto Mountains west and north of the Coachella Valley contributes ~79,000 acre-feet yr^{-1}, 5.9% of the total input. Over 40% of the Coachella Valley uses drip irrigation; tailwater disposal was prohibited in the 1950s. Agricultural runoff to the Sea from the Coachella Valley is therefore much reduced compared to the Imperial Valley (Colorado River Board of California 1992; US Bureau

of Reclamation 1998a). Before it enters the north end of the Salton Sea, the Whitewater River is renamed (and demeaned) as the Coachella Valley Stormwater Channel. See Nordland (1978) for a detailed history of Coachella Valley floods and attempts to control them.

5. Groundwater inflows are hard to determine, but it is estimated that ~50,000 acre-feet yr^{-1} enter the Sea (~3.7% of total inflows), with ~30,000 acre-feet yr^{-1} of this volume coming from the Coachella Valley with its high water table and permeable sediments, ~10,000 acre-feet yr^{-1} entering from the general area of San Felipe Creek, and only ~2000 acre-feet yr^{-1} coming from the Imperial Valley because of its mostly impermeable sediments. The remaining ~8000 acre-feet yr^{-1} come from all other perimeter areas (Colorado River Board of California 1992). Groundwater throughout the Salton Trough is saline, varying from an estimated 8 g l^{-1} in San Felipe Valley to 16 g l^{-1} in the Imperial Valley. (Salton Sea Authority and US Bureau of Reclamation 2000a).
6. The only other significant surface flow to the Sea is intermittent San Felipe Creek draining the Laguna and Santa Rosa Mountains (Fig. 4), whose 5,500 acre-feet yr^{-1} is negligible compared to other sources (Hely et al. 1966). San Sebastian Marsh (Ciéneguita del Tular, elevation −10 m) is biologically important. This marsh is a 23 km^2 area of permanent water and marsh at the confluence of four intermittent drainages: Carrizo, Coyote, Fish, and San Felipe Creeks, ~10 km upstream from the present Salton Sea (Fig. 4, at the junction of San Felipe Creek and the unnamed Carrizo Creek). Salt Creek on the east shore, labeled Salton Creek in Fig. 1 contributes much less, ~1,000 acre-feet yr^{-1}.
7. Seepage from the unlined Coachella Canal contributes an unknown but probably significant amount of water to the Sea (Fig. 5). Cutting off this important source of fresh water by lining major canals, especially the Coachella, with concrete might additionally stress the Salton Sea and its biota, as well as the excellent wildlife habitats of springs and seeps fed by underground seepage (Layton and Ermak 1976; Pryde 1999).
8. Natural runoff and rainfall are inconsequential (~46,500 acre-feet yr^{-1}, 3.5% of the total). Average rainfall is <7.5 cm yr^{-1}, but both total rainfall and its seasonal patterning are exceedingly variable; some years there is no rain at all (California Department of Water Resources 1970; Layton and Ermak 1976; Rowlands, 1995a). Winter cyclonic storms out of the Pacific Ocean provide the major rainfall to the Salton Trough, but summer rains (from México via Arizona), usually thunderstorms (erroneously called "monsoons"), can be significant. The southern Imperial Valley gets ~30% of its annual rainfall in the summer, declining northwards to 20% at Palm Springs in the Coachella Valley (Rowlands 1999a). Rare *chubascos* (late summer hurricanes which move northwards along the west coast of México) have sometimes dropped as much as 22.5 cm of rain in 24 to 48 hr. Such downpours can cause flash floods in mountain and desert streams, and can raise Sea elevations dramatically (Oglesby pers. obs.); Hurricane Kathleen in 1976 raised the Salton Sea nearly 20 cm in just one day. *Chubasco*s were of regular occurrence in the 20th century through 1939, but only three have hit California since, in 1976 and 1977.

It is important to realize that even had the Salton Sea not initially been formed by inept diversion from the Colorado River in 1905 to 1907, it would be the same size and composition now (Table I). Since 1925, increased volumes of irrigation wastewater have resulted in a nearly continuous rise in the Sea's elevation, with a temporary period of stasis in the mid-1960s and a rapid rise of ~15 cm yr^{-1} beginning in the early 1970s. In the late 1970s, above normal rainfall also contributed to a rising Salton Sea. With increasing efforts at water conservation by the Imperial Irrigation District, less agricultural water has been "wasted" to the Sea beginning in the late 1980s, leading again to surface-elevation stabilization. The surface elevation in 1984 was around −69 m and it was about the same in the late 1990s. Sea elevation varies by ~0.3 m within the year due to seasonal differences in evaporation and wastewater input, being highest in June and lowest in mid-autumn.

In 1981, 27 property owners, mostly from the southwest shoreline of the Salton Sea, won a suit against the Imperial Irrigation District over loss of lands and buildings to the rising Salton Sea and water-logging of soils adjacent to the shoreline. One of the findings of the California State Water Resources Board (1984, 1988) was that the Imperial Irrigation District secretly wasted ~550,000 acre-feet yr^{-1} of water that was permitted to go directly into drains, and thus into the Salton Sea, from main canals without ever being put on an agricultural field (spillwater). This spillwater wastage was in addition to the 550,000 acre-feet of tailwater discharged into the Sea through ordinary agricultural uses (California State Water Resources Control Board 1975, 1988; Coe 1981; Pryor 1981; California Reporter 433 Cal. App. 4 Dist. 1984; Matthews 1982; *Los Angeles Times* 17 August 1985; Breuer 1992; Colorado River Board of California 1992; deBuys 1999).

The Boulder Canyon Act of 1928 allocated California 4.4 million acre-feet yr^{-1} of Colorado River water, but also allowed California to take its proportional share of otherwise unused Colorado River water. Of this, the Imperial Irrigation District takes 3 million acre-feet yr^{-1}, with ~1.3 million acre-feet yr^{-1} ending up in the Salton Sea. As of 2000 California was actually taking ~5.2 million acre-feet yr^{-1}, well over its allotment.

There are many initiatives to force California to reduce its take to its allocated 4.4 million acre-feet yr^{-1}. In the Imperial Valley, ready availability of cheap, federally subsidized water, an extremely arid environment, intense heat, irrigation practices designed to flush salts from the fields, and reliance on water-intensive crops all contribute to the Valley's high water use (Cohen et al. 1999). There are ample opportunities for changed agricultural practices, water conservation, and marketing water outside the Salton Trough. One certain result is that much less water will enter the Salton Sea in the future, perhaps as little as ~800,000 to 850,000 acre-feet yr^{-1}, ~62% of present input (see below). This great reduction in inflow will have major effects on the Salton Sea ecosystem, and must be taken into account in any proposed "restoration" plan.

Chemical and Physical Limnology

The term salinity is properly used only for open-ocean seawater, and not for fresh waters and inland saline waters, either marine in derivation (thalassic) or athalassic, as non-seawaters do not show the ion ratios characteristic of open-ocean seawater. But it is convenient to write about the salinity of inland athalassic

waters, especially since many authors casually use this terminology and use silver chloride (AgCl) titration or salinometers to measure it. Hutchinson (1975) described the salinity of inland wàters as "the concentration of all the ionic constituents present." Salinity is expressed in grams per liter (g l^{-1}). One hundred percent open ocean seawater has a salinity of 35 g l^{-1}. There is no "normal" salinity for inland waters, just whatever the actual salinity might be.

The Salton Sea is vertically and horizontally homogenous (well mixed) except for small inshore areas where tributaries enter (Arnal 1961; Cook and Orlob 1997). Salton Sea water represents Colorado River water modified by passage through irrigated fields (soil leaching, exchange of chemicals with the soil, intense evaporation), with relatively higher concentrations of calcium ion (Ca^{2+}) and sulfate ion (SO_4^{2-}), and relatively lower concentrations of magnesium ion (Mg^{2+}), sodium ion (Na^{1+}), potassium ion (K^{1+}), and chloride ion (Cl^{1-}) as compared with ocean seawater (Table I). Carpelan (1961b) and Arnal (1961) summarized salinities and ionic compositions of the Salton Sea and the major rivers from 1907 to 1955. Lowest salinities in the Sea were found near the mouths of the three rivers. Arnal (1961) concluded that New River water mixed completely with Salton Sea water within ~10 to 13 km of its mouth, along the east side of the Sea.

During the 1960s and early 1970s, with Sea elevation more or less stabilized, its salinity rose at the rate of about 0.5 g l^{-1} yr^{-1}. With the increase in Sea elevation and volume since 1975 (~15 cm yr^{-1}) its salinity stabilized and even declined somewhat. In 1985, its salinity reached ~38 g l^{-1}, rising to 39 to 40 g l^{-1} by 1989, and to 40 to 47 g l^{-1} by 1999 (González et al. 1998; Hart et al. 1998; Oglesby pers. obs.).

Most attention has been, and is being, paid to increased salinity as the single most important problem facing Salton Sea biota (see below). Hagar and Garcia (1988) pointed out that a species' existence in relation to increased salinity in the Salton Sea could depend on any or all of the following circumstances:

- Direct mortality due to exceeding high salinity tolerance (see below).
- Reproductive failure at high salinities. Many studies indicate that this problem would occur at salinities below the limit for adult survival of a variety of species of fish and invertebrates (see below).
- Loss of food supply due to exceeding the food's tolerance for high salinity. Increasing salinity would change the trophic structure of the Salton Sea. Fewer species would be present, though overall invertebrate abundance might not diminish.
- The interaction of other physiological and biological factors with salinity to cause mortality or reduced reproduction.

As discussed by the Imperial Irrigation District (1994), Hagar and Garcia in 1988 found little information on the last two of these situations; limits to reproduction and adult salinity tolerance are discussed for many Salton Sea species (see below). The Imperial Irrigation District (1994) reproduced a lengthy table from Hagar and Garcia which estimated the severity of impact of increased salinity on Salton Sea biota.

It is sometimes stated that the Salton Sea is an alkaline lake. Available data indicate otherwise. The Salton Sea varied from *p*H 8.3 to 8.6 in winter and from *p*H 8.5 to 8.8 in summer in the 1950s (Arnal 1961; Carpelan 1961b). The lowest

measurement in the mid-1950s was *p*H 7.3 in mid-Sea bottom waters and the highest *p*H was 8.9 near the delta of the New River (Arnal 1961). In the 1970s through the 1990s, *p*H varied from 7.5 to 8.7 in the spring (Phelps and Anspaugh 1976; Salton Sea Authority and US Bureau of Reclamation 2000a; Coachella Valley Water District, pers. comm.; Oglesby pers. obs.). The usual *p*H (~8.3) of the Salton Sea is only slightly higher than that of the ocean (Sverdrup et al. 1942) and many ordinary freshwater lakes (Hutchinson 1975), and is considerably less than true alkaline lakes in the arid West, whose *p*H exceeds 9; for example, Mono Lake has a *p*H of 10 (Hutchinson 1975; Hammer 1986; Mono Basin Ecosystem Study Committee 1987).

*p*H measurements in irrigation drains and the three rivers in 1969–1975 varied from 7.3 to 8.5 (data of the California Department of Water Resources cited by Swajian 1976). Whitefield Creek in the Salton Sea State Recreation Area, which receives no irrigation wastewater, varies from *p*H 7.4 to 8.4 (higher values reflect Salton Sea water in the bottom of this stratified stream), and the concrete-lined Cleveland Street Spillway near North Shore, which contains irrigation drainwater, from *p*H 7.1 to 8.0 (Oglesby pers. obs.). These values are well within normal ranges for freshwater streams (Hutchinson 1975).

Always a saline river because of natural saline springs and marine and evaporite geological formations through which it flows, the salinity of the Colorado River increases sevenfold from its headwaters to Imperial Dam just above Yuma (Fradkin 1981). Salts leached from geological formations are responsible for 47% of the river's total increase in salinity. Additional causes of increased salinity of the river include irrigation returns (37%), export of pristine waters (3%), inputs of municipal and industrial wastes (1%), and evaporation from its many reservoirs (12%) (data of Colorado River Water Quality Improvement Program cited by Evans 1975; Fradkin 1981; Reisner 1993).

The Imperial Valley has little usable groundwater because of impermeable sediments and the absence of adjacent mountains to provide runoff, and relies entirely on imported Colorado River water for both agriculture and domestic uses. The Coachella Valley has groundwater but now is in overdraft. The Coachella Valley relies almost totally on Colorado River water for agriculture, while pumped groundwater is still used for domestic uses and the many golf courses (Kahrl 1978; Nordland 1978; Coachella Valley Water District 2000). Imported water for these valleys is diverted from the Colorado River through the All-American and Coachella Canals, and varies from ~0.5 g l^{-1} to 0.9 g l^{-1} (Oglesby pers. obs.). The salinity problem is much worse in the Valle de Mexicali downstream, with salinities as high as 2.7 g l^{-1} being reported (Fradkin 1981). The Valle de Mexicali uses only one-third to one-half the amount of water per hectare as the Imperial and Coachella Valleys.

Salinization of fields is a major problem in both Coachella and Imperial Valleys, because of naturally saline desert soils, irrigation with saline Colorado River water, high water tables, and intense evaporation (Nordland 1978; Breuer 1992; Reisner 1993; Oglesby pers. obs.). Even though the Imperial Valley is one of the most productive agricultural areas in the world with up to five crops per year, net cultivated acreage has declined in the past several decades due to salinization (Layton and Ermak 1976; Imperial County Agricultural Commission 1990; Breuer

1992). Breuer (1992) quoted Dunbier, "Thousands of acres have been abandoned because of this excessive moisture in what paradoxically is one of the driest parts of the desert." Underground tile drains (plastic pipes with small perforations through which water enters) have been installed in over 80% of the irrigated fields in both valleys, removing saline water downwards from crop root zones. This water is then pumped into surface drains by sump pumps; these drains flow to the Salton Sea. Water in drains in both valleys is too saline for irrigation or stenohaline freshwater biota (Oglesby pers. obs.). The biota of these drains is euryhaline.

The Salton Trough is one of the hottest places on Earth, comparable to the Persian Gulf and Red Sea regions. Maximum air temperatures continuously exceed 38°C more than 110 days per year (d yr^{-1}); the highest recorded summer temperature, 48.3°C, has occurred several times. Summer nighttime low temperatures are also among the highest on Earth. However, frost may occur on winter mornings. The frost-free period is >300 d yr^{-1} for 9 of 10 yr and >350 d yr^{-1} for 3 of 10 yr (Layton and Ermak 1976). The relative humidity is always low, ranging from ~18% to 33%, with lowest values in summer (California Department of Water Resources 1970; Layton and Ermak 1976; Rowlands 1995a).

Because of these dramatic differences in seasonal air temperature, the shallow Salton Sea varies greatly in seasonal temperature, particularly along its shorelines, from <10°C in the winter to as high as 36°C in the late summer, with even greater extremes in shallow shoreline pools (Barlow 1958a; Arnal 1961; Carpelan 1961b; Hely et al. 1966; Black 1980; Oglesby pers. obs.). Diurnal temperature variations at the shoreline and in pools are also great both winter and summer (Black 1980; Oglesby pers. obs.).

With an average depth of ~5 m and a maximum depth of only ~16 m, the Salton Sea is a very shallow body of water. Arnal (1961) provided details of wind-driven circulation patterns in the Sea. Recent field studies and simulations show two horizontal gyres: a stronger, counterclockwise gyre in the southern basin and a weaker, clockwise gyre in the northern basin. This horizontal circulation is driven by nearly constant northwesterly (north basin) and westerly (south basin) winds, strongest from late winter to late spring (Cook and Orlob 1997; Cook et al. 1998). This two-gyre horizontal circulation is confirmed by space photos, beginning with photos taken by Gemini V astronauts on 22 August 1965, which show a striking pattern of floating material, not identified in 1965. (One photograph was the cover photo for *Science* for 6 October 1972; see also Laflin 1998.) More recent space photos sometimes show the same two-gyre pattern, often clearly of patchy phytoplankton blooms as they are red in false-color infrared images. Another possibility for this floating material is rafts of dead fish. Silt plumes move counterclockwise along shore from the mouths of the New and Alamo Rivers, but do not reach the open Sea (contrary to Norris and Webb 1990).

Even if the Colorado River no longer contains much silt, the New and Alamo Rivers are always silty from agricultural runoff (LFR 1999; Oglesby pers. obs.) and continue to deposit silt at their deltas at the southern end of the Salton Sea. Arnal (1961) concluded from detailed calculations that agricultural wastewater contributed ~75% of the total sedimentary input to the Salton Sea, with the remaining sediment derived from the Salton Trough itself, shed from surrounding mountains.

Deep lakes may thermally stratify and not show complete vertical mixing for long periods of time; this probably occurred with Lake Cahuilla. In contrast, the shallow Salton Sea is a polymictic lake in terms of vertical stratification and mixis (Arnal 1961; Hammer 1986; Cook et al. 1998; Swan et al. 2000; Oglesby pers. obs.). But the Sea can stratify thermally almost any time of the year, doing so most frequently and for the longest time periods during the summer. Stratification is stronger in the northern basin (Cook et al. 1998). Surface to bottom temperature differences are not great during stratification, often no more than 3 to 5°C (Arnal 1961; Hely et al. 1966; Swan et al. 2000; Oglesby pers. obs.). The thermocline in summer is deeper nearshore than in the middle of the Sea (Swan et al. 2000). During thermal stratification, the concentration of O_2 below the pycnocline may drop to lethally low levels for fish; 0% oxygen saturation and concomitant increases in sulfide (S^{2-}) in the hypolimnion below 9 m are not uncommon during the summer, especially during periods of calm weather (Carpelan 1961b; Swan et al. 2000; Oglesby pers. obs.). Hurlbert (Salton Sea Authority and US Bureau of Reclamation 2000a) stated that 60 to 100% of the Sea's bottom is exposed to a concentration of O_2 <1 mg l^{-1}. Ekman grabs of the Sea bottom below 10 m often smell of H_2S (Oglesby pers. obs.). Horvitz (2000) stated that during some summer mixing events, there may be no O_2 found below 1.5 m. Since the Sea is so shallow, the pycnocline is not stable.

At any time of the year high winds may occur in the Salton Trough (Arnal 1961; Oglesby pers. obs.), often causing sand storms. Waves in the Sea may reach as high as 1 to 2 m, hazardous to small boats (Oglesby pers. obs.). When the Salton Sea turns over completely, it brings hypoxic and S^{2-}-rich (up to 5 mg l^{-1}) hypolimnic water to the surface and sometimes causes large fish kills (Swan et al. 2000; Oglesby pers. obs.). Fish may "gulp" air at the surface as a prelude to die-offs (Horvitz 2000).

The "tideless intertidal" zone.—A widespread misconception is that the Salton Sea has moon-driven tides (programs at the Visitor Center of the Salton Sea State Recreation Area; Pepper 1972, 1999; Karr 1985); this error has even seeped into the formal scientific literature (Raimondi 1992). Lunar tides are found only in the ocean and connected embayments. No inland body of water has lunar tides, not even Eurasia's Caspian Sea, the largest inland body of water in the world (Defant 1958). A day spent monitoring the shoreline water level of the Salton Sea, even casually, would easily reveal the absence of lunar tides (Oglesby pers. obs.). The fact that the Salton Sea does not display lunar tides was commented upon at least as long ago as 1934 by Cowles.

The Salton Sea might have low-amplitude seiches—wind-generated oscillations in lake level which may continue for some time after the wind dies down (Sverdrup et al. 1942; Hutchinson 1975)—but this has been little mentioned by anyone other than deBuys (1999), who misunderstood the process. Because of the generally northwesterly winds, the southeastern end of the Salton Sea has a "slightly" higher water level than at the northwest shore (Cook and Orlob 1997); this small rise may or may not be enough to initiate a seiche when the wind dies down. Seiches may also occur following earthquakes (Salton Sea Authority and US Bureau of Reclamation 2000a).

Studies in the tideless Baltic and eastern Mediterranean Seas show "intertidal"

zonation of a few species of tough algae and sessile animals, based on probabilities of long-term variations in water level caused by variations in both atmospheric pressure and wave action. From the standpoint of the biota, these changes in level are not regular and predictable as are tides, but zonation still occurs because of long-term differences in aerial and aquatic exposure (Segerstråle 1957).

Because of wind-caused wave action, "intertidal" algae grow on hard substrates at the edge of the Salton Sea, such as rip-rap, jetty rocks, utility poles, trees, and buildings. Brown filamentous diatoms (*Nitzschia sigmoides,* attached to *Calothrix* filaments) and the green alga *Enteromorpha* sp. are the major algae involved, harboring a small motile zoobenthos, particularly amphipods (*Gammarus mucronatus*) and water boatmen (*Trichocorixa reticulata*). There is limited vertical zonation over a vertical 0.3 to 0.6 m or so, with filamentous diatoms zoned above *Enteromorpha.* Because of the usually shallow photic zone ($\sim$1 m) and the limited extent of hard substrates, these benthic plants are only of local ecological importance. Barnacles (*Balanus amphitrite*) also occur in this "tideless intertidal" zone, feeding every time a wave washes over. Many small invertebrates live among the barnacles; Coe et al. (2000) reported 4468 individuals in a single 100 cm^2 area. Hard "intertidal" substrates are often coated with a crust of gypsum ($CaSO_4$), which is near saturation in the Salton Sea (D. Zenger pers. comm.; Oglesby pers. obs.).

Mini-estuaries.—The mouths of many drains and all three rivers form small estuaries with strong horizontal salinity gradients that may extend from a few meters into the drain to hundreds of meters, and with sometimes quite steep vertical salinity gradients as well (Oglesby pers. obs.). Estuarine aspects of these tideless mini-estuaries at the Salton Sea have been little studied. Though there are only limited data, low-salinity surface plumes from the New and Alamo Rivers apparently are dissipated within a relatively short distance of their entries into the Salton Sea (Arnal 1961; Salton Sea Authority and US Bureau of Reclamation 2000a). Throughout the remainder of the Sea, the water column is well mixed in terms of salinity both horizontally and vertically (Salton Sea Authority and US Bureau of Reclamation 2000a; Oglesby pers. obs.).

The estuary of Whitefield Creek in the Salton Sea State Recreation Area, whose lower channel was originally dug by backhoe $\sim$1968 (0.7 m deep, 1 to 1.5 m wide) had a $\sim$15 cm layer of 4 to 5 g l^{-1} water overlying a deeper layer of nearly full strength Salton Sea water of $\sim$38 to 40 g l^{-1} in the late 1970s. The halocline extended over a vertical distance of only a few cm, and was easily visualized because underlying Salton Sea water was turbid and overlying Whitefield Creek water was clear; the halocline was very sharp (Oglesby 1977, pers. obs.). In the 1970s there was a horizontal salinity gradient from nearly fresh water to Salton Sea water extending along the 1.6 km long jetties at Red Hill Marina; since then rising water levels have drowned the jetties, and the same gradient now occurs over a much shorter distance (Oglesby pers. obs.).

Similar mini-estuaries are found at the mouths of drains, which are often nearly completely blocked off from the open Salton Sea by barnacle shell "sand" bars, forming stratified ponds. For example, the pool at the mouth of the Cleveland Street Spillway on 24 February 1996 was strongly stratified: at the surface, salinity 2 to 3 g l^{-1}, 17.6°C, and 9.08 milligrams per liter (mg l^{-1}) O_2; at the bottom, 1

m deep, salinity 14 g l^{-1}, 22°C, and 6.97 mg l^{-1} O_2 (Oglesby pers. obs.). Because of changing Sea water levels and wave action moving the "sand" bars, ponds often change size, depth, position, and gradients of salinity, temperature, and O_2. Drain-mouth ponds and associated riparian vegetation form a complicated, valuable, and variable habitat for aquatic and semi-aquatic biota (Oglesby pers. obs.). At times, such as Whitefield Creek in the late 1970s, salinity gradients and stratification lead to variations in vertical distributions—fresher water invertebrates in less saline surface water, and Salton Sea biota in higher saline bottom water (Oglesby 1977). By the mid-1980s, the entire distribution pattern of biota in Whitefield Creek had shifted markedly when the rising Salton Sea forced the upper, low salinity layer out of its artificial channel and into adjacent marshes (Oglesby pers. obs.).

The *horohalinicum* is a term introduced by Kinne (1971) for a salinity "boundary" or "barrier" at ~5 to 8 g l^{-1} for distributions of estuarine biota (see also Oglesby 1978). The horohalinicum is the transition zone between ion ratios characteristic of fresh water (usually dominated by high bicarbonate [HCO_3^{1-}] and Ca^{2+}) and those of seawater (dominated by Cl^{1-} and Na^{1+}). Most freshwater and marine animals, even if euryhaline, cannot cross the horohalinicum because of physiological limitations. Euryhaline estuarine organisms often are able to cross the horohalinicum, and may be vastly abundant as individuals but not diverse as to species. At the Salton Sea, desert pupfish (*Cyprinodon macularius*), tilapia (*Oreochromis mossambicus*), sailfin mollies (*Poecilia latipinna*), and some other fish cross the horohalinicum readily, as can pileworms (*Nereis succinea*), thiarid snails (*Thiara granifera* and *T. tuberculata*), some crustaceans, and insects such as water boatmen (Oglesby 1993, pers. obs.; see below). None of these salinity-related distributions have been well studied at the Salton Sea.

Shoreline pools.—A biologically interesting feature of the Salton Sea is its shoreline pools, varying from a fraction of a meter in all dimensions to 15 × 200 m, and sometimes even to 1000 m in the longer dimension (usually parallel to shore) and up to 0.5 to 1.0 m or more deep, separated from the Sea by narrow "sand" bars of broken barnacle shells (Barlow 1958a; Black 1980; Oglesby pers. obs.). These pools can be common along gently sloping shorelines, such as at the mouth of the Cleveland Street Spillway, Mecca Beach, Bombay Beach, Red Hill Marina, around Obsidian Butte, and Desert Shores. Most shoreline pools are initially filled by wave action from the immediately adjacent Salton Sea. Some are also fed by "freshwater" drainage from inland—drains, seepage from unlined canals and drains, springs along faults, and occasionally small streams. Small pools, fed only by wave action, are usually ephemeral. Large pools are often permanent (Oglesby pers. obs.).

Most shoreline pools start out at the salinity of the Sea and increase in salinity as they desiccate, reaching at least as high as 105 g l^{-1} (Oglesby pers. obs.). Shoreline pools are much more variable in salinity, temperature, *p*H, and O_2 concentration than the Sea itself, though only the deeper ones show vertical temperature stratification (Barlow 1958a; Oglesby pers. obs.). Diurnal temperature ranges of 15 to 20°C are not uncommon, and temperatures as high as 43°C have been recorded (Black 1980; Oglesby pers. obs.). *p*H varies from 7.1 to 9.4 (Oglesby pers. obs.).

Shoreline pools may have a diversity of often highly colored algae and aerobic and anaerobic bacteria. Pools can be yellow, orange, light green, dark green, pink, red, or purple, depending on the dominant algae or bacteria, which in turn reflect differences in salinity, O_2, temperature regimen and extremes, nutrients, and depth (Oglesby pers. obs.). Larger pools contain populations of desert pupfish, mosquitofish (*Gambusia affinis*), longjaw mudsuckers (*Gillichthys mirabilis*), and sometimes bairdiella (*Bairdiella icistia*) (Barlow 1958a; Black 1980); desert pupfish have been rare in recent years (A. Schoenherr, pers. comm.; Oglesby pers. obs.). Macroscopic invertebrates seen in these pools include water boatmen, pileworms, barnacles, nematodes, harpacticoid copepods, heleid and ephydrid fly larvae, and dragonfly nymphs (Table VII; Barlow 1958a; Oglesby pers. obs.). Salton Sea phytoplankters are also found in these pools (Oglesby pers. obs.).

Biology of the Salton Sea

The biology of the Salton Sea is unlike that of any other body of water, fresh or salt. All the important organisms in the Sea came from somewhere else (Gulf of California, Gulf of Mexico, North Atlantic Ocean, Africa, Southeast Asia, Polynesia, tropical Indo-Pacific), usually accidentally and almost always from ocean or inland salt waters, not from fresh water. Most invertebrate and phytoplankton species are well known as highly invasive and are often cosmopolitan. Many attempts have been made to introduce fish and other animals of commercial or sport importance to the Salton Sea. Nearly all attempts failed, either immediately or after changes in the Sea's salinity, but those introductions that succeeded have done so spectacularly. There is only a very limited number of macroscopic species living in the Salton Sea (low diversity), but they often occur in immense numbers. Food webs are short and more like straight-line food chains than in most other bodies of water. The Salton Sea is highly unusual in lacking any significant predators on zooplankton; all the major food chains to sport fish and birds depend ultimately on benthic detritus and detritivorous polychaete annelids. Despite popular opinion, the hypereutrophic Salton Sea, nourished by fertilizer runoff from agricultural fields, is very much "alive." Despite its age, the study edited by B. W. Walker (1961) remains the best description of the biology of the Salton Sea. Stuart Hurlbert at the Center for Inland Waters at San Diego State University is the leader of a current comprehensive biological study of the Salton Sea quasi-marine ecosystem. Much of this important work was not yet published in 2000.

1. Invertebrates and Aquatic Plants

Bacterioplankton.—There has been no study of pelagic bacteria or their ecological roles in the Salton Sea, even though they are often abundant in other saline lakes, up to 10^8 cells ml^{-1} in saline African lakes, and up to 10^7 cells ml^{-1} in Nevada's Pyramid Lake and California's Mono Lake. In these athalassic saline lakes, bacterioplankton densities are higher by several orders of magnitude than in ordinary freshwater lakes (Mono Lake Ecosystem Study Committee 1987). Hammer (1986) reviewed a number of studies on saline lake bacterioplankton.

Phytoplankton and primary productivity.—Primary productivity in the Salton Sea is by extraordinarily abundant phytoplankters, chiefly dinoflagellates and di-

atoms. Recent reports (Hurlbert et al 2000, Salton Sea Authority and US Bureau of Reclamation 2000a; Salton Sea Authority and US Bureau of Reclamation 2000b) have greatly increased the number of identified and unidentified species in a diversity of algal and protozoan taxa (see Table IV), none of which is likely to be restricted to the Salton Sea.

Dinoflagellates are always planktonic, their great density often turning the Sea's water the color of murky tea. None cause "red-tides," which in some coastal waters can cause major fish mortalities. See Table IV for a list of reported dinoflagellates.

Diatoms are mostly planktonic but some species also occur on "intertidal" rocks as brownish filaments representing non-integrated colonies of many cells, likely *Nitzschia sigmoides,* growing attached to bluegreen algal filaments (usually *Calothrix*). Other species live on the surface of muds and other soft substrates, including algal mats, as long as they are within the photic zone (Lange and Tiffany 2000). Some diatom tests found in the Salton Sea may represent freshwater diatoms washed into the Sea by rivers (Lange and Tiffany 2000). About 92 species—chiefly of marine planktonic origin—were identified by the late 1990s, some new to science. See Table IV for a list of reported diatoms, by no means all that are present. Diatoms dominate the phytoplankton assemblage in summer and fall, with densities of $\sim 10^6$ cells l^{-1} (Lange and Tiffany 2000).

Fertilizers in agricultural wastewater have turned the Sea into one of the world's most eutrophic lakes, fresh or saline. Surprisingly, there have been very few measurements of nutrient concentrations in agricultural drainwaters or in the Salton Sea itself (Tables II, III). The great differences in nutrient concentrations between inflowing water and the Salton Sea in 1968 to 1969 were attributed both to dissolved nutrients being taken up by Salton Sea biota and to sedimentary sequestration in organic detritus (US Department of the Interior and The Resources Agency of California 1969). Carpelan's (1961b) data showed a strong summer maximum in ammonium ion (NH_4^{1+}) both in the epilimnion and at the bottom of the hypolimnion at a site off Desert Shores; nitrate ion (NO_3^{1-}) and phosphate ion (PO_4^{3-}) did not show much seasonal variation. Carpelan (1961b) regarded his NO_3^{1-} analyses as probably unreliable. His data, summarized in Table III, were from four stations; highest values were found at a shallow station near Mullet Island, strongly influenced by irrigation runoff from the nearby Alamo River. González et al. (1998) discussed these earlier data, but did not provide any new data for the present Salton Sea; they thought that nutrient inputs were about the same in the 1990s as in 1970. Additional data were reported by the Salton Sea Authority and US Bureau of Reclamation (2000a).

Recent proposals for a massive tilapia harvest to lower "excess" PO_4^{3-} concentration in the Sea to ameliorate the Salton Sea's hypereutrophic state seem not to be based on recent PO_4^{3-} measurements (Table III). The Salton Sea Authority and US Bureau of Reclamation (2000a) assumed that PO_4^{3-} was the limiting nutrient in the Salton Sea, as dissolved orthophosphate concentrations "have been below the detection limit of [0.053 μM] on several occasions." The Authority suggested harvesting 200 kg tilapia per hectare per year (ha^{-1} yr^{-1}) (= 20,000 metric tons from the entire Salton Sea), which would remove only 10% of the incoming PO_4^{3-} yr^{-1} (González et al. 1998; Costa Pierce and Riedel 2000; Riedel and Costa-Pierce 2000; Salton Sea Authority and US Bureau of Reclamation

2000a). Even the Authority admitted that commercially harvesting tilapia would not reduce the Sea's hypereutrophic status to any significant degree. The question is, then, why do it at all?

There are no laboratory or field studies which have determined which nutrient actually limits Salton Sea productivity. While most freshwater lakes are PO_4^{3-}-limited (Vollenweider 1968 as cited by Cagle 1998), others are limited by NO_3^{1-} or NH_4^{1+}, by cofactors for photosynthesis such as manganese (Mn), or by trace metals such as iron (Fe) and molybdenum (Mo) (Hutchinson 1975; Moss, 1988; Lebo et al. 1994; Evans and Prepas 1997). California's saline Mono Lake is limited by NH_4^{1+} (Melack and Jellison 1998). Salton Sea diatoms are primarily marine in origin (Table IV) and most marine diatoms are limited by Fe (Falciatore et al. 2000). Since the photic zone is so shallow, usually <1 m, Salton Sea productivity may be light-limited, rather than nutrient-limited. While Secchi disc values (which measure transparency) may be as great as 3 m in mid-winter (photic zone ~9 m), during summer algal blooms they are often <0.3 m, with a photic zone of only 1 m (Arnal 1961; Tiffany et al. 2000b; Oglesby pers. obs.). Even in so shallow a lake most of the water column does not receive enough light for photosynthesis. Appropriate experiments on what limits Salton Sea productivity need to be done before "solutions" to nutrient loading, including fish harvesting, are chosen. In any case, it would be much more important to reduce inputs of agriculture-derived nutrients at their sources, but this is not proposed by the Salton Sea Authority and US Bureau of Reclamation (2000a).

In 1954 and 1955, Salton Sea primary productivity was ~0.75 grams carbon per square meter per day ($g\ C\ m^{-2}\ d^{-1}$) (range: 0.11 to 1.9 $g\ C\ m^{-2}\ d^{-1}$), as much as 10 metric tons dry weight $ha^{-1}\ yr^{-1}$, ~1.7 times the maximum productivity of oceanic upwelling systems (Arnal 1961). These data demonstrate that the Sea has long been hypereutrophic (Carpelan 1961c). A primary productivity estimate made in 1968 and 1969 was even higher, an average of 4.4 $g\ C\ m^{-2}\ d^{-1}$ over the year, and as high as 5 $g\ C\ m^{-2}\ d^{-1}$ during the summer (US Department of the Interior and The Resources Agency of California 1969). Tiffany et al. (2000b) measured highest chlorophyll concentrations in late winter, declining to a late summer low reflecting frequent summer stratification.

In Mono Lake and laboratory experiments with Mono Lake water and its phytoplankton, gross primary productivity decreased by 10% for every 10 $g\ l^{-1}$ increase in salinity over the range of 97 to 140 $g\ l^{-1}$. An unnamed diatom did not survive above 185 $g\ l^{-1}$, while an unnamed green alga survived to at least 237 $g\ l^{-1}$ (Mono Lake Ecosystem Study Committee 1987). The high-salinity-tolerant alga *Dunaliella salina,* (a red-colored green alga) not now found in either Mono Lake or the Salton Sea, is an aquaculture species in the Imperial Valley and could easily colonize the Sea when conditions become appropriate. *Dunaliella* grew well in 200 $g\ l^{-1}$ Mono Lake water (Mono Lake Ecosystem Study Committee 1987). Studies need to be done with Salton Sea phytoplankton to assess sensitivity of individual species and overall primary production to increased salinity.

The Salton Sea can vary from brown to brick red to light green, reflecting blooms of different species of dominant phytoplankters. The typically brown color of Salton Sea water, indicative of high densities of dinoflagellates, does not represent a "dead" lake as popularly believed, but a hypereutrophic lake with vastly abundant phytoplankton.

Zooplankton.—The abundant phytoplankters are fed upon by very few species of zooplankton, primarily a copepod (*Apocyclops dengizicus*), a rotifer (*Brachionus rotundiformis*), larval stages of benthic pileworms and barnacles, and fingerlings of sciaenid fish (Tables VII, VIII; Carpelan 1961d; Kuhl and Oglesby 1979; Dexter 1993; Oglesby pers. obs.). These few zooplankton species can be exceedingly abundant throughout the year (B. W. Walker 1961; Oglesby pers. obs.), though Tiffany et al. (2000b) reported a zooplankton low in summer during stratification, and also after summer mixing elevated H_2S throughout the water column.

The abundant cyclopoid copepod *Apocyclops dengizicus,* initially described as a new species restricted to the Salton Sea, *Cyclops dimorphus,* by Kiefer (1934), is known from inland and usually saline lakes on several continents. Johnson (1953) provided a detailed morphological description of this species (as *C. dimorphus*). *A. dengizicus* lives in Australian lakes in salinities ranging from 4 to 69 g l^{-1} and can tolerate salinities at least as high as 107 g l^{-1} Salton Sea water for at least 60 d (Dexter 1993). In the Salton Sea, development from eggs to sexual maturity takes 10 to 15 days (Carpelan 1961d). Dexter (1993) reported slower and more variable developmental rates varying from 2 weeks to 2 months, with successful reproduction at salinities from as low as 0.5 g l^{-1} to as high as 45 g l^{-1}; there was reduced reproductive success at salinities as high as 68 g l^{-1}. Carpelan (1961d) concluded that 10 to 15 generations could be produced each year. He collected no *A. dengizicus* during the winter, but Dexter (1993) found *A. dengizicus* year-round near the shoreline, with only reduced density rather than absence in colder months. In the laboratory, *A. dengizicus* is an active predator, feeding upon rotifers, *Artemia* nauplii, protozoans, and insect larvae, as well as on phytoplankton (Dexter 1993; Hart et al. 1998). Dexter (1993) pointed out that laboratory experiments on this and other invertebrates may not mimic actual conditions in the Salton Sea very well—laboratory experiments provide stable physical conditions (O_2 concentration, temperature, salinity) and adequate food and usually lack predators and competitors.

The monogonont rotifer *Brachionus* is the most numerous Salton Sea zooplankter during most of the year except mid-winter, with highest densities in the summer (Kuperman et al. 2000). Recent taxonomic work, primarily in the laboratory but supported by field studies, indicates that the cosmopolitan *B.* "*plicatilis*" is a species complex composed of at least two different species (*B. plicatilis* and *B. rotundiformis*) and several additional clonal groups that do not mate with each other (Gómez and Serra 1995; Segers 1995; Gómez and Snell 1996; Gómez et al. 1997; Serra et al. 1998). *B. rotundiformis* form SS seems to be the (only?) species in the Salton Sea, both now and in the 1950s; it is the taxon in this complex most tolerant of high temperatures and high salinities (Serra et al. 1998; Kuperman et al. 2000; Tiffany et al. 2000b). Earlier work around the world published under the name *B.* "*plicatilis*" may have actually been done on that species, or on *B. rotundiformis,* or on a mixture of both species. Recent work that distinguishes the two species demonstrates that there are physiological and ecological differences between them. *B. rotundiformis* is "slightly more tolerant" of high salinities than *B. plicatilis* (Fielder et al. 2000) and has a higher energy content (Yufera et al. 1997). It is therefore not a given that the biology of true *B. plicatilis* is the same as that of *B. rotundiformis.*

Brachionus plicatilis and *B. rotundiformis* are non-selective filter-feeders on planktonic algae, protozoa, bacteria, and yeasts (K. F. Walker 1981; Hammer 1986; Turner and Tester 1992; Arndt 1993; Jurgens and Jeppesen 2000). *B. plicatilis* (and presumably *B. rotundiformis*) is a strongly euryhaline hyperosmotic osmoconformer as demonstrated in populations from other geographical areas, surviving in from 1 to 97 g l^{-1}; a report of survival in 200 g l^{-1} is probably a typographical error (K. F. Walker 1981; Hammer 1986). Oxygen consumption is not much affected by salinity in most of the range tested, but is depressed in 1 g l^{-1} (K. F. Walker 1981). *B. "plicatilis"* is eurythermal, "likely" to withstand extreme temperature ranges from 5 to 29°C (K. F. Walker 1981). Salton Sea rotifers obviously withstand even higher temperatures, to well over 30°C. K. F. Walker (1981) and Hammer (1986) reviewed the many physiological studies on *B. plicatilis* (some perhaps including *B. rotundiformis,* not yet recognized as a distinct taxon), commenting that most of the studies had been done on laboratory populations so that little was known about actual ecology of these rotifers in the field.

Both *Brachionus* species show cyclic changes in size and morphology during the year (cyclomorphosis) at the Salton Sea and elsewhere (Carpelan 1961d; Hammer 1986; King and Serra 1998). Some populations of *B. "plicatilis"* have both sexual (mictic) and asexual (amictic, parthenogenetic) reproduction, depending on season, temperature, salinity, and other factors (Hammer 1986; Gómez et al. 1997). Salinity affects the timing of parthenogenetic and sexual cycles in Israel, with no sexual cycles at salinities in excess of 35 g l^{-1} (Lubzens et al. 1985, 1997). No males were found in Salton Sea *Brachionus* by Carpelan (1961d). He speculated that rotifer reproduction in the Salton Sea was only parthenogenetic (amictic), not sexual, with winter spent as dormant cysts which hatch in May or June. Summer reproductive cycles could be completed in 1 to 2 wk. Since the Salton Sea is now ~43 to 47 g l^{-1}, reproduction obviously does take place at these higher salinities.

Carpelan (1961d) thought that no Salton Sea animals ate living *Brachionus*; rather, he wrote, the rotifers die, sink to the bottom, and become detritus. But many aquaculture operations conduct mass laboratory culture of *Brachionus* as food for aquacultured fingerlings of important food fishes (Hansen et al. 1997; Lubzens et al. 1997). Fingerling and juvenile Salton Sea fishes and zooplankton such as copepods may well feed on *B. rotundiformis* (Kuperman et al. 2000). The actual ecological role of *B. rotundiformis* in the Salton Sea is little known.

See below for discussions of the abundant and ecologically significant zooplanktonic larvae of pileworms and barnacles. Other, apparently less ecologically significant, zooplankters are listed in Tables IV and VII (B. W. Walker 1961; Hurlbert et al. 2000; Small and Gebler 2000; Oglesby pers. obs.).

Bacteriobenthos.—It must be emphasized that the most unusual aspect of Salton Sea ecology is that plankters, both plant and animal, are generally *not* eaten in great numbers by pelagic planktivores. Rather, both phytoplankters and zooplankters die and sink, along with feces and dead fish, to the bottom where they are broken down through bacterial decay to black, rich, odiferous, slimy, jelly-like, organic detritus. Detritus, including bacteria, decayed plant and animal material, and reworked fish and invertebrate feces, is the basic food source for pile-

worms and some other benthic invertebrates, ultimately leading to the huge population of sport fish (B. W. Walker 1961). Bacterial decomposition processes have been briefly studied in Mono Lake (Mono Lake Ecosystem Study Committee 1987), but not in the Salton Sea.

Exposed mud flats in drowned fields nearly surrounded by dikes are sometimes colored in rich pinks, reds, and purples by photosynthetic anaerobic bacteria, arrayed in concentric patterns (Oglesby pers. obs.). Bluegreen algae (Cyanobacteria) are common in the Salton Sea, chiefly as benthic mats on solid substrates such as pilings and rocks, and on soft bottoms in areas with little wave action, such as drowned fields (Table IV). Wood et al. (2000) reported a great diversity of bluegreen algae in the Salton Sea, especially filamentous species in algal mats (Table IV). Bluegreen mats often float to the surface on their own photosynthetic O_2 (Carpelan 1961c; Oglesby pers. obs.). Floating bluegreen algal mats are responsible for much of the characteristic summer odor (H_2S) of the Salton Sea, rather than sewage as widely believed (*contra* Wambaugh 1992). See Hammer (1986) for a review of microbial mats in saline lakes.

Phytobenthos.—Carpelan (1961c) mentioned the green algae *Cladophora* sp. and *Enteromorpha* sp. as growing in drains, but did not report them in the Sea itself. *Enteromorpha* is now common in the Sea on hard substrates, both on "tideless intertidal" rocks along with filamentous diatoms and "subtidally" to the depth of the shallow photic zone, rarely more than 1 m. *Enteromorpha* is particularly common in low salinity areas, such as at the mouths of drains and the three rivers (Oglesby pers. obs.). See Tables IV and V.

No vascular plants grow in the Salton Sea itself (Table V). An attempt was made in 1957 to introduce turtle grass, *Halodule* (formerly *Diplanthera*) *wrighti* (Cymodeaceae), from the Gulf of Mexico in Texas but it did not establish (Barnard and Gray 1968, 1969; Oglesby pers. obs.). Feldmeth (1980) suggested that both *Halodule* and the cosmopolitan ditch grass, *Ruppia maritima* (Ruppiaceae) might still grow on the seawards side of the Whitewater Marsh at the north end of the Salton Sea, but there is no actual evidence that either genus grows in or near the Salton Sea (Oglesby pers. obs.).

Many springs, streams, drains, and permanent shoreline pools are dominated by the noxious and highly invasive alien weedy shrubs salt cedar (tamarisk, *Tamarix ramosissima*) and giant reed (*Arundo donax*), which create impenetrable thickets and poor wildlife habitat. Giant reed can reach >10 m high and dewater shallow springs and streams. Its shallow root system makes it very susceptible to uprooting by flood waters, leading to rapid dispersal downstream. Salt cedar debris raises the salt content of the soil underneath, making it even more difficult for native plants to germinate and grow; it too is extremely difficult to eradicate (England and Laudenslayer 1995; Broussard et al. 2000). Either weedy shrub can completely replace native riparian and marsh vegetation. Both flowing water in streams and shoreline erosion send floating salt cedar and giant reed masses into the Salton Sea, where they serve as impermanent substrates for barnacles (Oglesby pers. obs.). The native common reed (*Phragmites australis*) and cattails (*Typha* sp.) also form dense marshes in similar locations, but are much more valuable as wildlife habitat; cattail (*Typha* spp.)-bulrush (*Scirpus* spp.) marshes are particu-

larly important for rails (Tables V, X). All these plants are salt tolerant, salt cedar being the most euryhaline.

Fungi.—A number of aquatic fungi have been reported for the Salton Sea by Anastasiou (1961, 1962, 1963), who collected them on drowned *Tamarix aphylla* trunks in the southern Salton Sea. Though he named several of these as new species, and even one new genus, Anastasiou regarded them all as widespread (though little studied) in the Pacific Ocean and North America; some were primarily terrestrial but obviously can survive and grow in the Salton Sea, while others were primarily aquatic. Ascomycetes included: *Amphisphaeria verrucuclosa, Ceriosporopsis halima, Halosphaeria mediosetigera, Leptosphaeria orae-maris, Lulworthia medusa, L. opaca, Peritrichospora integra,* and *Pleospora herbarum.* Fungi Imperfecti included: *Acrospeira levis, Alternaria radicina, A. tenuis, Botryotrichum piluliferum, Clavariopsis bulbosa, Contortospira varia, Fusarium solani, Pericomia prolifera, Scopulariopsis* sp., *Stachybotris atra, S. subsimplex.* Mycelia Sterilia included *Populaspora halima.* These fungi are all metabolizers of dead wood; other potential fungal habitats in the Salton Sea have not been investigated.

Zoobenthos.—In the open Salton Sea there are only two major benthic animals, pileworms and barnacles, both extraordinarily abundant. At the Sea's margins, particularly near hard substrates, there are additional invertebrates—protozoans, nematodes, other polychaetes, amphipods, harpacticoid copepods, glass shrimp, and insects (Tables IV, VII). Shoreline pools and estuaries of many drains, and probably of the three rivers, additionally have euryhaline snails and more species of insects and crustaceans (Tables VI, VII).

The vastly abundant pileworm, *Nereis* (*Neanthes*) *succinea,* was probably introduced in 1929 when California Department of Fish and Game Warden Glidden purchased buckets of live bait in San Diego and dumped them into the Salton Sea in order to establish a food base for striped bass (*Morone saxatilis,* Serranidae), to be introduced the following year. Striped bass and most of the bait animals were not successful, but *Nereis succinea* succeeded beyond anyone's imagination. The pileworm was described as a new species (*Neanthes saltoni*) only 30 years after the Salton Sea came into existence as a freshwater lake and only 7 years after its actual introduction (Hartman 1936). *Nereis succinea,* a North Atlantic species widely dispersed by shipping and introductions of oysters elsewhere in the world, does not now occur in San Diego Bay, but is abundant in parts of the Los Angeles-Long Beach Harbor system and in San Francisco Bay (Oglesby 1965, pers. obs.). Whether the pileworm occurred in San Diego Bay in 1929 but has since gone locally extinct, or the bait Warden Glidden bought came from several locations, including Los Angeles Harbor, will never be known (Anonymous 1929, 1930a,b, 1931a,b; J. Fitch, pers. comm.).

Use of the generic name *Nereis* here follows the practice of Smith (1958) and Pettibone (1963), who argued that generic splitting should not be based on juvenile morphologic characters not found in sexually mature adults (in this case, a special seta lost during metamorphosis). The names *Hediste, Neanthes,* and *Nereis* are treated here as subgenera of *Nereis,* not as separate genera.

Eggs, trochophores, and small juveniles of *Nereis succinea* are abundant in the plankton year-round (Oglesby pers. obs). Carpelan (1961d) found a summer max-

imum of planktonic stages. Planktonic juveniles of ~6 to 9 setigers settle to the bottom (Carpelan and Linsley 1961a), but do not metamorphose into sexually mature adults for at least 6 to 12 months. Over its wide native and introduced range, *N. succinea* is generally regarded as an unselective bacterivore and detritivore. While no work has been done on this species, Lucas and Bertru (1997) found enzymes appropriate for bacteriolysis in the related deposit feeder *Nereis (Hediste) diversicolor.*

At the Salton Sea, benthic *Nereis succinea* feeds on rich organic detritus, burrowing in any soft substrate as well as barnacle shell "sand," including shoreline pools in salinities as high as 65.5 g l^{-1} (Barlow 1958a; Oglesby pers. obs.). Benthic abundance in nearshore waters is highest from January through April (Kuperman et al. 2000). Growth rates are also fastest in the spring (Carpelan and Linsley 1961b). In 1954 to 1958, there was a standing crop of pileworms of up to 67 metric tons per hectare (ton ha^{-1}) in spring, dropping to 16 metric ton ha^{-1} in late summer, with a yearly mean of 28 metric ton ha^{-1} (Carpelan and Linsley 1961a); they estimated a standing crop of 13.2 million kg for the entire Salton Sea in the fall. Detwiler et al. (2000) reported densities up to 85,500 worms per square meter in rocky shorelines. Burrowing pileworms increase the depth of the oxidized layer of the sediments and assist in breaking down tough fecal pellets, such as those egested by the amphipod *Gammarus mucronatus.*

Nereis succinea occurs at its highest densities in the depth range of ~1 to ~8 m (Carpelan and Linsley 1961a; Oglesby, pers. obs.). Pileworms disappear from deeper waters (>~9 m) during the summer, apparently due to hypoxic hypolimnic waters; they recolonize these deeper waters every autumn; Detwiler et al. (2000) reported total pileworm loss below 2 m during the summer. There is much variability in the maximum depth at which pileworms can be found in the spring, from 8 m to the very deepest part of the Sea off North Shore at 15 m (Oglesby pers. obs.). Some of this spring variability in maximum depth for pileworms may relate to variations in bottom topography or patchy anaerobic bottom waters.

Pileworms are of the greatest significance in the food chain of the Salton Sea, being the major food of bairdiella, young orangemouth corvina (*Cynoscion xanthulus*), and tilapia, as well as wintering eared grebes (*Podiceps nigricollis*). Particularly during the summer, reduced or eliminated populations of benthic pileworms throughout much of the Sea bottom lead to huge summer die-offs of bairdiella, recognized since a few years after its introduction in the early 1950s (Hanson 1972; Kuhl and Oglesby 1979; Costa-Pierce 1998a; Oglesby pers. obs.).

Nereis succinea benthic immatures (atokes) are euryhaline, with maximum salinity for survival 80 to 90 g l^{-1} (lower at higher temperatures); 65 to 70 g l^{-1} is the practical highest salinity for long-term survival (Oglesby 1965, pers. obs.; Hargreaves 1968; Hogue 1970; Hanson 1972; Kuhl and Oglesby 1979; Duncan 1986; Simpson et al. 1998). *N. succinea* can live in salinities (both Salton Sea water and ocean seawater) as low as 5 to 8 g l^{-1}, approximately the horohalinicum (Oglesby 1965, pers. obs.; Hogue 1970; Kuhl and Oglesby 1979; Duncan 1986); the report by Foster (1972) that *N. succinea* can live and reproduce in fresh water is in error. Reproduction is not successful above 50 g l^{-1}, due to a salinity bottleneck during cleavage (Kuhl and Oglesby 1979).

Benthic pileworm atokes metamorphose into swimming, pelagic, non-feeding, sexually mature adults (epitokes, heteronereids) which swarm at the surface at

night for breeding and can be attracted to lanterns or flashlights (Carpelan and Linsley 1961b; Linsley and Carpelan 1961; Kuhl and Oglesby 1979; Oglesby pers. obs.). Swimming heteronereids are particularly vulnerable to fish predation (Oglesby pers. obs.). Pileworm heteronereids die after breeding. Pileworm larvae can be found in the plankton year-round (Oglesby, pers. obs.), but Kuperman et al. (2000) found larvae most abundant in March, least abundant in summer, and then of increasing abundance beginning in November.

The East Coast estuarine spionid *Streblospio benedicti,* now widely distributed on the West Coast, is common in muddy clays in the Salton Sea at depths of 2 to 12 m; the first Sea record was 1999 (D. Dexter pers. comm.). On the East Coast, different populations of S. *benedicti* display either of two reproductive modes, one lecithotrophic in which yolky fertilized eggs are brooded by females in burrows followed by brief, non-feeding planktonic stages, the second planktotrophic with small eggs that hatch, develop, and feed entirely in the plankton (Levin et al. 1991; Levin and Bridges, 1994; Bridges and Heppell 1996). It has not yet been reported which breeding mode is used by Salton Sea *S. benedicti.* Spionids in general feed on benthic detritus and bacteria, brought to the mouth in ciliated grooves that run the length of two long palps that are extended over the substrate or into the water column. See Table VII for other annelids, including two other spionids.

The euryhaline acorn barnacle *Balanus amphitrite* is abundant on any solid substrate: rocks, wood, buildings, trees, barnacle shells, dense mud, the bottoms of boats left in the water overnight, soft drink cans, and beer bottles, as well as at least one of twenty-four Navy aircraft that crashed during nighttime training exercises during and after World War II. This particular plane crashed on 30 December 1947 and the two crewmen survived (*Los Angeles Times* 15 June 1999). Local television news tapes, taken in March 1999 (KNBC, Los Angeles), showed an almost intact Grumman Avenger torpedo bomber at ~16 m depth several miles off the Salton Sea State Recreational Area, festooned with barnacles. The finding of this wrecked airplane covered with living barnacles demonstrates that barnacle larvae can settle out even at 16 m depth in the Salton Sea, if the substrate is appropriate. On soft substrates, barnacles are abundant down to ~3 to ~4 m, living barnacles attached to dead barnacle shells forming softball-sized clusters (Oglesby, pers. obs.). Barnacles are so abundant in the Sea that much of the shoreline is covered with thick deposits of "sand" of broken and intact barnacle shells. Clumps of living barnacles thrown up by wave action can survive long periods in the larger shoreline pools (Barlow 1958a; Oglesby pers. obs.).

Balanus amphitrite was introduced in the early 1940s, probably from San Diego Bay on seaplane floats and buoys brought in by rail to the Navy's Salton Sea Test Base at the southwestern end of the Salton Sea (5334 ha, around two thirds submerged by the Sea; established 1942, mostly abandoned in the 1970s, decommissioned 1989) (Salton Sea Authority and US Bureau of Reclamation 2000a). An alternative barnacle source is the Gulf of Mexico, larvae carried in ballast water of Navy seaplanes flown in from Texas (Cockerell 1945b; Hilton 1945; Carpelan 1961d; Linsley and Carpelan 1961; Newman and Abbott 1980; Raimondi 1992). *B. amphitrite* is probably originally native to the Indo-West Pacific (Newman and Abbott 1980). It is often found in estuaries and has been dispersed by shipping throughout the world.

The Salton Sea barnacle has a muddled taxonomic history. It was originally described as a new subspecies (*Balanus amphitrite saltonensis*) within a decade of its introduction (F. L. Rogers 1949), based only on adult morphology, different from that of the same species introduced earlier into southern and central California coastal estuaries, bays, and lagoons. Henry and McLaughlin (1975) regarded the Salton Sea population as a subspecies distinct from *B. amphitrite amphitrite,* again based only on adult morphological differences. Salton Sea barnacles have thinner, more fragile shells and are taller than ocean barnacles (F. L. Rogers 1949; Oglesby pers. obs.).

Linsley and Carpelan (1961) thought that crowding accounted for the distinctive Salton Sea barnacle morphology. *Balanus amphitrite* transferred from Salton Sea water to ocean seawater immediately starts to secrete new shell characteristic of ocean seawater barnacles, demonstrating that the two different shell morphologies are environmentally determined (W. Newman pers. comm.; Oglesby pers. obs). Adult morphological differences (based on measurements of tergal plates) vanish when barnacles from the Sea are cultured in ocean seawater. Raimondi (1992) believed that morphological differences in adults were based entirely on environmental differences (perhaps because of the relatively higher Ca^{2+} and SO_4^{2-} concentrations in the Salton Sea). However there are persistent larval differences (Raimondi 1992). Compared to ocean seawater larval development, Salton Sea barnacle larval development lasts longer, cyprids reach a larger size, and are unpigmented.

Raimondi (1992) concluded that the three persistent larval differences between Salton Sea and ocean *Balanus amphitrite* were genetically and evolutionarily based, and argued for natural selection rather than genetic drift as the operative evolutionary mechanism. Flowerdew (1985) showed no genetic divergence in allozymes between ocean and Salton Sea populations for 31 alleles at 11 loci. Sixtus (1978) found phenotypic differences in temperature adaptation between coastal and Salton Sea barnacles, as well as a reduction in heterogeneity in two allozymes in Salton Sea barnacles. Flowerdew (1985), however, found no reduction in heterozygosity in Salton Sea barnacles, presumably because the inoculum in the early 1940s was not small enough to cause a genetic bottleneck or founder effect. Sixtus (1978) concluded that intense selection was occurring at the Salton Sea, and would lead to increased divergence of coastal and Sea barnacles. Raimondi (1992) made the important general point that no one would recognize any genetic differentiation between Salton Sea and coastal *B. amphitrite* if only adult phenotypic characters were used for analysis.

Balanus amphitrite has been collected at salinities as high as 65 g l^{-1} in Salton Sea shoreline pools (Oglesby pers. obs.), and as high as 75 g l^{-1} in the hypersaline Laguna Madre in Texas (Simmons 1957). In Salton Sea microcosms, barnacles survived to 70 to 80 g l^{-1}, with much reduced survival at salinities up to 100 g l^{-1} (Simpson and Hurlbert 1998). Growth was fastest at 48 g l^{-1} and slowest at 65 g l^{-1}. There were differences in shell morphology at different salinities, with diameter, height, and wall thickness being greatest at 48 g l^{-1}. Simpson and Hurlbert (1998) found no difference in shell material strength with salinity, but the force required to break intact barnacles was highest at 48 g l^{-1} because of changes in overall shell morphology at different salinities. Larval barnacles survive up to 86.4 g l^{-1}, but with reduced survival above 58 to 74.9 g l^{-1}; low salinity stress

at early developmental stages influences low salinity tolerance at later developmental stages (Crisp and Costlow 1963; Perez 1994; Qiu and Qian 1999). Simpson and Hurlbert (1998) suggested that barnacles would disappear from the Salton Sea when the salinity climbed to 70 to 80 g l^{-1}, with a concomitant loss of habitat for several currently important benthic invertebrates.

Adult, benthic *Balanus amphitrite* is a filter-feeding zooplanktivore, like most barnacles, as are its planktonic nauplius larvae. Developing nauplius larvae cannot be supported by bacterivory alone (Gosselin and Qian 1997).

Acorn barnacles such as *Balanus amphitrite* are hermaphrodites, but normally indulge in cross-fertilization; they can self-fertilize if necessary (W. Newman pers. comm.). After internal fertilization, eggs are brooded in the mantle cavity, hatching as nauplii. Nauplius larvae are released to the plankton where they filter-feed through six molts. Sixth stage nauplii metamorphose into non-feeding planktonic cyprid larvae which seek out appropriate substrates on which they settle and metamorphose into sessile adults. Perhaps because of greater availability of hard substrates and greater density of adults, barnacle larvae are more abundant near shore than in the open Sea (Carpelan 1961d; Oglesby pers. obs.). Daily settlement rates can exceed 30 cyprids cm^{-2}, leading to dense aggregations (Linsley and Carpelan 1961). Ocean coastal populations of *B. amphitrite* reproduce only when water temperature exceeds 20°C (Newman and Abbott 1980); Salton Sea barnacles spawn over the range 17 to 27°C, and perhaps to 33°C (Carpelan 1961d). There are two spawning peaks, with highs in spring and fall and lows in summer and winter, but nauplii and cyprid larvae are present in the plankton all year (Carpelan 1961d; Oglesby pers. obs.). Kuperman et al. (2000) found nauplius density greatest from January through April.

The benthic amphipod *Gammarus (Marinogammarus) mucronatus* was apparently introduced from the Gulf of Mexico in 1957 as a contaminant during the attempted introduction of turtle grass *Halodule* (Barnard and Gray 1968, 1969). A detritivore, microherbivore, and predator (González et al. 1998; Hart et al. 1998; Cruz-Rivera and Hay 2000), *G. mucronatus* is abundant, particularly near rocks (as many as 3183 in one 100 cm^2 patch: Coe et al. 2000), in barnacle shell debris, and shoreline pools with salinities as high as 65.5 g l^{-1} (Oglesby pers. obs.). Detwiler et al. (2000) reported densities as high as 126,000 m^{-2} on rocks. At high salinities in laboratory microcosms, a decline in *G. mucronatus* density led to an increase in water boatman density, presumably because of release from predation (Hart et al. 1998). The reproduction of *G. mucronatus* in Massachusetts was studied by LaFrance and Ruben (1985). *G. mucronatus* is reported to tolerate salinities from 4 to 50 g l^{-1}, but not above 57 g l^{-1}, upper laboratory limits contradicted by field observations at the Salton Sea (Hart et al. 1998; Oglesby pers. obs.). There was no successful reproduction in laboratory microcosms above 39 g l^{-1}, even though gravid females were found in salinities as high as 65 g l^{-1} (Simpson et al. 1998). Simpson et al. (1998) suggested that *G. mucronatus* suffered osmotic stress at salinities above 39 g l^{-1}. *G. mucronatus* is fed upon by sargo and perhaps by tilapia. See Table VII for other amphipods.

The extraordinarily euryhaline anostracan brine shrimp *Artemia* sp. does not now live in the Salton Sea itself (Hart et al. 1998; Oglesby, pers. obs.), probably because of fish predation, even though the Salton Sea Authority and US Bureau of Reclamation (2000a) stated it was present. Probably only when all fish and

zooplanktivores are lost in the Salton Sea due to high salinity will *Artemia* colonize the Sea, as brine shrimp have in Mono and Great Salt Lakes.

The only other large benthic crustacean found in the Salton Sea itself is the glass shrimp *Palaemonetes paludosus* (Table VII). This euryhaline freshwater shrimp, native to the US East Coast, first became established in ditches below Hot Mineral Spa in the Imperial Valley (St. Amant and Day 1972). Though glass shrimp were deliberately introduced into the lower Colorado River system by the California Department of Fish and Game in 1958 (Hayden and Rinnyo 1963) and are now widespread in the Colorado River system, St. Amant and Day (1972) believed that the Hot Mineral Spa population was derived from a local tropical fish farm. *P. paludosus* could probably survive the present high salinities of the Salton Sea, but its close association with benthic vegetation such as *Chara* and *Enteromorpha* suggests that it will not become abundant in the Sea itself. *P. paludosus* is regularly found in the *Typha* and *Juncus* marsh at the mouth of Whitefield Creek, as well as upstream in ditches near Red Hill Marina, and in the delta of the Alamo River (Oglesby pers. obs.). Glass shrimp are important food for largemouth bass and other introduced cichlids (Hayden and Rinnyo 1963).

Horvitz (2000) reported a "live crab" found in Varner Harbor, Salton Sea State Recreation Area, in the mid-1990s. No one else has reported crabs in the Salton Sea; it is likely that this crab was dumped after not being used as bait. Other aquatic crustaceans of the Salton Trough are listed in Table VII.

Insects are sometimes abundant in the Salton Sea itself as well as in shoreline pools. The widespread New World corixid water boatman *Trichocorixa reticulata* (initially named a new subspecies, *T. verticalis saltoni* in 1948) is common on and near rocks and is often abundant in hypersaline shoreline pools at the Salton Sea and in saline waters elsewhere (Table VII; Barlow 1958a; Lebo et al. 1982; Oglesby pers. obs.). Water boatmen have been found in salinities as high as 47 g l^{-1} in the Salton Sea and in much higher salinities in shoreline pools, to at least 70 g l^{-1}, and in mud volcano pools up to 105 g l^{-1} (Barlow 1958a; Parker and Knight 1992; Oglesby pers. obs.). *T. reticulata* has been found in salinities as high as 190 g l^{-1} in San Francisco Bay salt ponds (Balling and Resh 1984). Hart et al. (1998) cited a laboratory experiment in which *T. reticulata* survived in 300 g l^{-1}, and a thesis by Cox which reported that *T. reticulata* reproduced over a range from 5 to 148 g l^{-1}; the Salton Sea Authority and US Bureau of Reclamation (2000a) cited water boatmen reproducing at field salinities as high as 100 g l^{-1}. *T. reticulata* is an excellent osmoregulator to at least 100 g l^{-1}, but is never collected in pure freshwater, apparently due to osmoregulatory failure at really low salinities (Sanguinetti 1980). Its distribution relative to the horohalinicum has not been studied.

Water boatmen rest on the bottom, but swim rapidly away from shadows and potential predators (the Salton Sea Authority and US Bureau of Reclamation [2000a] is in error in calling them surface-dwelling). Adults can fly, and so can abandon pools that have become too saline. The *Los Angeles Times* (3 April 1989) reported that after a massive winter die-off of tilapia in the Salton Sea, "unprecedented swarms" of water boatmen, presumably released from fish predation, "took wing and descended on homes and vehicles for miles around." During an unusually wet year, when the salinity of the Great Salt Lake dropped significantly

(from 100 to 50 g l^{-1}), *T. reticulata* became much more common, and *Artemia* dry biomass was reduced from 720 to 2 milligrams per cubic meter (mg m^{-3}). There was a 10-fold reduction in community filtration rate, a 20-fold increase in chlorophyll a concentration, a 4-fold decrease in water clarity, and perhaps a decrease in soluble nutrients. Invertebrate predators may be important in structuring simple food webs such as those in saline lakes (Wurtsbaugh 1992).

At the Salton Sea *T. reticulata* is omnivorous, feeding on small algal and other cells, small insects, detritus, and other zoobenthos. It thus competes with *Gammarus mucronatus* for food (Lebo et al. 1982; Simpson et al. 1998). *G. mucronatus* is also a predator on *T. reticulata* (Simpson et al. 1998). Hammer (1986) reviewed the many studies on the physiology and reproduction of *Trichocorixa reticulata.*

Brine flies may be abundant. *Ephydra riparia* (Ephydridae) is the most common, but shoreline flies of other families (e.g. Heleidae) are also present; both are present in shoreline pools (Table VII; Barlow 1958a; Oglesby pers. obs.). In laboratory microcosms, *E. riparia* larval and adult densities increased at higher salinities, surviving well from 17 to 65 g l^{-1} (Simpson et al. 1998). At the Salton Sea, brine flies have been found at salinities as high as 43 g l^{-1}, and have been reported in other salt lakes with salinities as high as 300 g l^{-1} (Simpson et al. 1998). *Ephydra* spp. are strongly hypo-osmotic when adapted to higher salinities (as high as 330 g l^{-1} in the Great Salt Lake: Salton Sea Authority and US Bureau of Reclamation 2000a), and hyperosmotic when living in salinities below the horohalinicum (Hammer 1986). Larvae feed on algae. Hammer (1986) reviewed a number of studies on the biology of *Ephydra* spp. Many other Salton Trough aquatic insects are listed in Table VII.

Empty marine gastropod and bivalve mollusc shells are often found along the Salton Sea shoreline in areas frequented by fishers, but no living molluscs are known from the Sea itself. Beached shells are presumably from molluscs brought in as live bait. Most common are shells of the cockle *Protothaca staminea,* the jackknife clam *Tagelus* spp., and both species of mussels found along the California coastline, the native *Mytilus californianus* and the introduced Old World *M. gallo-provincialis* (see McDonald et al. 1991 for evidence that true *M. edulis* does not occur on the US West Coast). One time we found 11 empty shells of the tropical Indo-Pacific marine snail *Rhinoclavus vertegus,* whose local provenance is unknown (Oglesby pers. obs.). A report of a live octopus found in the 1970s has not been repeated (Horvitz 2000; J. Carlton pers. comm.; J. Fitch pers. comm.); no octopus prey live in the Sea. Euryhaline clams and snails live in drains and shoreline ponds, and their shells may wash into the Sea, especially *Corbicula* and *Thiara* (Table VI).

Two species of Old World freshwater snails in the prosobranch family Thiaridae (sometimes called Melaniidae) are common to abundant in some shoreline pools, most drains, springs, and other desert waters throughout the Coachella Valley and probably also the Imperial Valley. They are *Thiara* (*Tarebia*) *granifera mauiensis* and *Thiara* (*Melanoides*) *tuberculata.* Current taxonomic practice is to put both species in the same genus, *Thiara,* but many, scientists, especially parasitologists, continue to separate the two species into two genera, here treated as subgenera (Taylor 1981).

Thiara granifera is native to southeast Asia, China, and much of Polynesia

including Hawai'i, but it has been widely introduced throughout the world. *T. granifera* was first found in the US in Lithia Spring, Florida, and was believed to have been initially introduced to mainland US from Hawai'i around 1940 (Edmondson 1959). It was later reported in drainages associated with the San Antonio Zoo in Texas (Murray 1964 and later publications). Carolina Biological Supply Company listed *T. granifera* in its 1964 catalog, but the listing was later deleted (Murray 1971b). Murray (1971b) found both thiarid species for sale in aquarium shops "in many areas of the country." Both *Thiara* species were probably widely dispersed through the aquarium trade and from there into springs and streams around the country (R. T. Abbott 1952; Murray 1971b; Roessler et al. 1977). The earliest published California record (1969) of *T. granifera* is from the Avenue 82 drain on the northwest side of the Salton Sea (Taylor 1981; D. Taylor, pers. comm.), but A. Schoenherr (pers. comm.) said that he had seen this snail in Coachella Valley drains even earlier. R. T. Abbott (1952) provided a detailed description of the external and internal anatomy of *T. granifera.*

Thiara tuberculata is slightly larger than *T. granifera* (2 to 4 cm in the Coachella Valley: Oglesby pers. obs.; rarely to 7 to 8 cm in Texas: Murray 1975). Its native distribution in the Old World is from Africa to southeast Asia and some of the western Indo-Pacific islands; it too is widely introduced outside its original range. In the US its distribution now includes at least Maryland, Florida, Louisiana, Texas, Oregon, Nevada, Arizona, and California, where it was first reported in 1972 in a drainage ditch near the Salton Sea (Murray 1964, 1971b; Murray and Wopschall 1965; Dundee and Paine 1977; Roessler et al. 1977; Taylor 1981; Riggs 1984; Williams et al. 1985; Hershler 1998). *T. tuberculata* was first noticed in Whitefield Creek in the Salton Sea State Recreation Area in 1988, where it was rare compared to *T. granifera* (Oglesby 1993). Search revealed an immense population in the concrete-lined Cleveland Street Spillway in North Shore, along with sometimes equally dense populations of *T. granifera,* up to many thousands per square meter (Oglesby 1993, pers. obs.; M. Fasnow pers. comm.). Mixed populations of both *Thiara* species are found in many, perhaps most, drains throughout the Coachella Valley (Oglesby 1993 pers. obs.). We have not explored the Imperial Valley for either species.

Thiara tuberculata may outcompete native snails and rare fishes in desert springs, seeps, and streams in the western US, including several species of pupfish (*Cyprinodon* spp.) and rare native snails. In San Antonio, Texas, both thiarid species invaded the type locality of the native snail *Goniobasis comalensis* (Pleurocercidae), which has since become extremely rare (Murray 1970). *T. tuberculata* was introduced to the Caribbean island of Martinique in 1979, followed by rapid colonization of the entire island (Pointier et al. 1998), and is also on the nearby island of Guadeloupe (Pointier and Augustin 1999). Neither thiarid species outcompeted the other on Martinique, and there seemed to be no adverse effects on native aquatic biota, except for several species of *Biomphalaria,* intermediate hosts of schistosomiasis. Pointier (1999) regarded the introductions of both thiarid species into the Caribbean as beneficial, as there has been a great reduction in human schistosomiasis due to successful competition with *Biomphalaria* spp.

Both thiarids are primarily apomictic parthenogenetic live-bearers, releasing tiny (1 to 2 mm) shelled (up to 4 whorls) snails at the rate of one or two every day from the brood pouch, a diverticulum from the mantle cavity (R. T. Abbott

1952; Oglesby pers. obs.). The brood pouch may contain over 200 juveniles in a full range of developmental stages (R. T. Abbott 1952). Parthenogenetic populations of *Thiara tuberculata* are entirely female, and can be either diploid or polyploid. The rare males (3% of an Indian population) are only polyploid; no males have been found in diploid populations (Jacob 1957, 1958). Stoddart (1983) described from 0% to 30% males in different populations of *T. tuberculata* (as *T. balonnensis*) in Australia. Though it was rare, Australian males did participate in reproduction in sexual populations, as indicated by parent-offspring and allele-frequency analyses (Jarne and Delay 1991; Hauser et al. 1992; Jarne and Stadler 1995). Males have also been reported in some populations of *T. granifera* (Chaniotis et al. 1980b; Murray 1982; Heller and Farstev 1990; Brande et al. 1996). It is not easy to distinguish the sexes externally in either species. *T. tuberculata* becomes reproductively mature when the shell aperture attains 3.5 mm; they live only 2 years in Hong Kong, usually breeding only the second season (Dudgeon 1989). R. T. Abbott (1952) came to the same conclusion about a number of populations in Guam and Florida. In several Caribbean islands *T. granifera* lives around 3.5 years (Pointier et al. 1993b).

Shiroma (1990) studied reproduction in *Thiara granifera* as a function of salinity (test range: Whitefield Creek water at 3 g l^{-1} to Salton Sea water of 30 g l^{-1}), counting both numbers of juveniles in the brood pouch and the rate at which juveniles were released from the brood pouch. The maximal reproductive rate was at 10 g l^{-1} ($\sim$1 juvenile per day), declining only a little at lower and higher salinities. Reproduction was successful at 30 g l^{-1}; more casual observations suggest successful reproduction at considerably higher salinities (Oglesby pers. obs.). High salinities in the range found in the Salton Sea (up to 47 g l^{-1}) may not be limiting to reproduction of either *Thiara* species (Oglesby pers. obs.).

Because of their parthenogenicity and viviparity, both thiarids are highly dispersible. We always found snails on our wading shoes, and A. Schoenherr (pers. comm.) found snails on his fish seines used in drains. Birds could easily transport either species in mud on feathers or feet. It is possible that the entire population of each species in the Salton Trough is clonal, derived from one initial introduction each, as has been found by Stoddart (1983, 1985) for *Thiara tuberculata* (as *T. balonnensis*) in Australia. Preliminary study of DNA diversity using the Random Amplified Polymorphic DNA technique and the polymerase chain reaction is suggestive of single clones for each species in the Salton Trough (Bishop 1993), but not confirmed (Liao 1996). All individuals of each species tested by Bishop (1993)— 66 *T. tuberculata* and 33 *T. granifera* from various sites in the Coachella Valley—were morphologically and genetically identical. Just one founder snail of each species could have given rise to all the populations of these two species in the Coachella Valley.

Three distinct morphologies of *Thiara tuberculata* occur on Martinique, with decline in one morph consequent to introduction of a different morph (Pointier et al. 1993a; Samadi et al. (1999). These authors suggested that competition between morphs was responsible for this replacement. Parthenogenetic polyploid *T. tuberculata* have high densities of dinucleotide repeats; genotypes were wholly transmitted from mothers to offspring, suggesting that different shell morphotypes are genetic clones (Samadi et al. 1998, 1999). In Martinique, two morphs (clones) hybridize (Samadi et al. 1999).

Several published and unpublished laboratory experiments have investigated variations in physiological responses to variations in salinity, in part to determine which physical or chemical feature of the Salton Sea might prevent its colonization by either species of thiarid. In our work at the Salton Sea, laboratory media were made from appropriate mixtures of charcoal-filtered habitat water from Whitefield Creek and from the Salton Sea at Mecca Beach, both in the Salton Sea State Recreation Area. Such mixtures preserve the natural Salton Sea horohalinicum, somewhat higher than the horohalinicum salinity in European and American estuaries fed by true fresh water (Kinne 1971; Oglesby 1978, pers. obs.).

While they are usually described as freshwater snails, Salton Trough populations of both thiarids are extremely euryhaline. The upper salinity limit for *Thiara granifera* in the mini-estuary of Whitefield Creek (~12 to 14 g l^{-1}) is markedly lower than its laboratory tolerance of the same waters, up to 30 g l^{-1} for several months, and up to 65 g l^{-1} and even higher for shorter periods of time (Oglesby 1980, 1993, pers. obs.; Fastnow 1989; Robinson 1993). There are no published reports of *T. granifera* tolerating high salinities in the field away from the Salton Trough or in any other laboratory. *T. tuberculata* has been reported living in low salinities in Louisiana (up to 3 g l^{-1}: Dundee and Paine 1977), United Arab Emirates (~6 to 7 g l^{-1}: Ismail and Arif 1993), and Florida (up to 3 to 6 g l^{-1}, but with one record of 30 g l^{-1} in a tidal mangrove swamp: Russo 1974; Roessler et al. 1977).

Ranges of laboratory salinity tolerance are 0 to 65 g l^{-1} for Salton Trough *Thiara granifera,* and 0 to 90 g l^{-1} for *T. tuberculata,* ranges which would be notable for an animal of marine evolutionary origin, but which are especially noteworthy as these two species, their genus (or genera), and their family Thiaridae (or Melaniidae) are of evolutionarily freshwater origin (Morrison 1954). Below ~10 g l^{-1} (approximately the Salton Sea horohalinicum) down to laboratory tap water of 0 g l^{-1}, extracellular fluids of both species are well regulated, being strongly hyperosmotic and hyperionic to the medium. Like many estuarine polychaetes and other euryhaline invertebrates of evolutionarily marine origin, above the horohalinicum both species of *Thiara* are hyperosmotic osmoconformers. Extraorganismal water in the mantle cavity is neither osmotically nor ionically regulated, but the fluid of the brood pouch is strongly regulated in snails living in low salinities (Christ 1980; Swift 1986). Salinity tolerance of *T. tuberculata* is higher than that of *T. granifera,* and, remarkably, *T. tuberculata* appears to hyporegulate at salinities in excess of 65 g l^{-1}. Regulation begins to break down at ~80 g l^{-1}, and no snails survived above 90 g l^{-1} (Christ 1980; Oglesby 1980, 1993; Swift 1986; Robinson 1993; Oglesby and Fastnow pers. obs.). Clearly, high salinity is no barrier to colonization of the Salton Sea or its shoreline pools by either thiarid.

Oxygen consumption of Salton Trough *T. granifera* did not change between 0 and 20 g l^{-1}, declined only slightly at higher salinities, and was still strong at 45 g l^{-1}, the highest salinity tested (Bauriedel 1990). Oxygen consumption increased with study temperature, as one would expect.

Both species of thiarids tolerate hypoxic conditions well. *T. tuberculata* withstands anaerobic conditions: 98% survival after 24 hr and 25% survival after 48 hr; the latter revived without apparent damage when returned to normoxic water

(Von Brand et al. 1950). Murray (1964) reported that *T. granifera* in Texas not only tolerated low O_2 concentrations, but appeared to grow better in hypoxic waters. *T. granifera* survived in closed bottles for at least 4 days at 0.8 mg l^{-1} O_2, and had unlimited survival from 2.5 mg l^{-1} O_2 to 100% O_2 saturation (Fastnow 1989). One population of *T. tuberculata* lives in a sulfide-rich stream in Israel where H_2S concentrations ranged from 0.1 to 7.3 mg l^{-1}; in the laboratory, adult snails survived "oxygen-depleted" water with up to 3.4 mg l^{-1} H_2S (Heller and Ehrlich 1995). Juveniles were less tolerant of high-sulfide waters. Both in the Salton Trough and in the laboratory, *T. granifera* and *T. tuberculata* do not climb above the water surface, suggesting that they do not breathe air (Oglesby pers. obs.). *T. granifera* does not survive desiccation well (Chaniotis et al. 1980a), but *T. tuberculata* is moderately tolerant of desiccation (Dudgeon 1989). There is no indication in these studies that O_2 concentration would limit the distribution of either thiarid species at the Salton Sea, at least in shallow waters.

Both species of *Thiara* are eurythermal. Studies (Texas: Murray 1971b; Florida: R. T. Abbott 1952; Puerto Rico: Chaniotis et al. 1980a; Guam: R. T. Abbott 1952; Salton Trough: Oglesby pers. obs.) indicate that *T. granifera* can survive from 7°C to at least 40°C. Salton Trough thiarids are found in waters that get no colder than ~10°C; they can be found in waters at least as warm as 37°C (Oglesby pers. obs.). The actual range of temperatures at the Salton Sea is unlikely to limit the distribution of either species of *Thiara.*

Both thiarid species feed on detritus, bacteria, microalgae, and decaying macrophytes. They are typical of herbivorous prosobranchs in having a crystalline style to assist in digestion (R. T. Abbott 1952; Fish 1955; Roessler et al. 1977; Dudgeon and Yipp 1985; Oglesby pers. obs.). These feeding habits may put them in competition with other detritivores, perhaps including desert pupfish.

Taken together, these laboratory physiological investigations indicate that both species of *Thiara* could live in the Salton Sea—extremes of salinity, O_2 concentration, and temperature in the Sea are all well within physiological limits of both species. Why, then, don't they live in the Salton Sea? Fastnow (1989) experimentally maintained *Thiara granifera* in small wire mesh cages (15 cm cubes) in a shoreline *Typha* pool with a very silty bottom at the mouth of Whitefield Creek; salinity, temperature, and O_2 concentration were all well within physiological limits, but this pool did not have thiarids at this time. Most caged snails died within 3 to 4 weeks, but some caged snails were still alive after >2 months, when the experiment was terminated. These experiments were conducted in fall and spring, not summer when water temperatures would have been at their highest and O_2 concentration perhaps at its lowest. Fastnow's (1989) results suggest that the soft silty substrate in this particular pool was unsuitable for snails (they were always found on the cage sides or plant stems, not on the silty substrate). Lack of a suitable substrate may be an explanation for their absence in the Salton Sea proper.

There are potential snail predators in the Salton Trough such as tilapia (another tilapia, in Zimbabwe, *Sargochromis codringtoni,* readily eats *Thiara tuberculata* as well as other snails: Chimbari et al. 1997), Louisiana red crayfish, and terrestrial-based predators such as raccoons (*Procyon lotor*), herons, egrets, rails, and white-faced ibis (*Plegadis chihi*). We find broken shells in probable bird feces along dikes beside drains inhabited by snails. None of these potential predators

has a salinity boundary around 10 to 14 g l^{-1}, the upper salinity limit we have found for both thiarids in the Coachella Valley. It seems doubtful that predation keeps either thiarid species from colonizing the Salton Sea or the estuaries of drains. Why neither thiarid colonizes any part of the Salton Sea itself remains a mystery.

Cockerell (1945b) mentioned the presence of unidentified foraminiferan protozoans in the Salton Sea. F. L. Rogers (1949) listed 13 genera of benthic Foraminifera in shallow sediments of the Salton Sea; Arnal (1958, 1961) discussed distribution patterns and some ecological aspects of 20 species in 15 genera in the Salton Sea. Foraminifera were more abundant near shore and in river deltas than offshore, a distribution Arnal (1961) attributed to lower sediment *p*H in the deeper parts of the Sea. Linsley and Carpelan (1961) reported foraminiferans in shoreline sands and barnacle shell debris. Both groups reported a number of malformed tests. Because of their taxonomic affinities to Gulf of Mexico species, Arnal (1961) suggested that most foraminiferan introductions into the Salton Sea came by way of ballast water in Navy seaplanes from Texas during the 1940s (Table IV).

Linsley and Carpelan (1961) and Simpson et al. (1998) listed a number of other benthic and demersal protozoans in the Salton Sea, particularly ciliates and a large flagellate; we find ciliates in bluegreen algal mats and in shoreline pools (Table IV; Small and Gebler 2000; Oglesby pers. obs.). Hurlbert et al. (2000) and Small and Gebler (2000) identified over 40 ciliate species (Table IV). Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.

Arnal (1958) reported the presence of testate amoebae of two genera. Linsley and Carpelan (1961) also reported amoebas and radiolarians (Table IV), concluding that biomass represented by protozoans was small, relative to total algae and detritus. Forty-five different species of naked or lobose amoebas, at densities ranging from 14,500 to 237,000 cells per liter were identified by Rogerson and Hauer (2000). They pointed out that these amoebae, which feed on organic detritus and bacteria tightly bound to sediment particles, may be ecologically important in the Salton Sea.

Linsley and Carpelan (1961) and Dill and Cordone (1997) listed known introductions of invertebrates into the Salton Sea as of the late 1950s, nearly all of which failed to establish. Surely many more invertebrate species have been introduced during the past century, both accidentally and on purpose, for which official records are lacking.

Desert springs, streams, seeps, irrigation canals, drainage ditches, and other desert freshwater and athalassic saline habitats.—These aquatic habitats have an expectable array of aquatic plants (Table V) and aquatic invertebrates (Tables VI and VII); the tables are surely incomplete. Dominant in unlined sections of the Coachella Canal (salinity 0.5 to 0.9 g l^{-1}) were Asiatic river clams, the hydropsychid caddisfly *Smicridea utico,* the oligochaetes *Aelosoma* sp. and *Chaetogaster* sp., and chironomid midges. Concrete-lined portions of the canal supported large populations of *S. utico* and the lepidopteran larva *Parargyractis confusalis (*Marsh and Stinemetz 1983).

A preliminary non-quantitative report of invertebrates in San Sebastian Marsh in San Felipe Creek was provided by Lebo et al. (1982). Temporally and spatially

variable marsh salinities (~4 to 5 g l^{-1} up to ~9 g l^{-1}, with some salinities as high as 30 g l^{-1}) may be representative of habitats of invertebrates in drains. Overall insect diversity was low, higher on muddy and silty substrates and lower on harder sands and muds.

Not much work has been done anywhere on smaller, less conspicuous, invertebrates, such as worms, and there have been few studies even elsewhere of the ecology or physiology of these euryhaline freshwater invertebrates.

2. Amphibians, Reptiles, and Mammals

Amphibians.—No amphibians are known from the Salton Sea itself, but several species are found in drains and canals, springs, streams, and marshes close to the Sea, a few of which are slightly euryhaline (Table IX). See McClanahan et al. (1994) for a discussion of adaptations of desert anurans to desert life. The most widespread and commonest anuran is the introduced bullfrog (*Rana catesbeiana*), a large frog native to the US southeast. Bullfrog tadpoles, which usually metamorphose after 2 yr (perhaps only 1 yr in warm desert waters), compete with desert pupfish and other aquatic animals for food, including tadpoles of native frogs and toads. Adult bullfrogs are carnivorous, serious predators of native amphibians, small fish including desert pupfish, and even baby waterbirds (Stebbins 1985). Bullfrogs are one of the most noxious introductions to the Salton Trough and to California in general.

See Table IX for other Salton Trough amphibians. Most native amphibian species are undergoing severe, even catastrophic, population declines, often attributed to bullfrogs and habitat destruction. A contributing factor may also be chytridiomycosis, first described in 1998 from dead amphibians on several continents, including *Rana* spp. and *Bufo* spp. in nearby Arizona and Colorado, including the rare *Rana yavapaiensis* (Daszak et al. 1999, 2000), which may or may not be the correct name of the never-to-be identified euryhaline "*Rana pipiens*" studied by Ruibal (1959, 1963) in San Sebastian Marsh. Chytrids are ubiquitous fungi that lack hyphae and metabolize such polymers as keratin, a major component of amphibian skin; *Batrachochytridium dendrobatidis* seems to be the species involved in the arid Southwest.

Reptiles.—No reptiles are known from the Salton Sea, but several species are found in drains and canals. See Table IX.

Mammals.—There are no aquatic mammals in the Salton Sea, but one species occurs in drains and canals, often close to the Sea, the muskrat (*Ondatra zibethicus bernardi*). See Table IX.

California Department of Fish and Game issues lists of Colorado Desert Endangered, Rare, Threatened, and Special Concern species of invertebrates (only insects), plants, reptiles, and mammals. All these are terrestrial species with no connection to the Salton Sea or to aquatic habitats in the Desert, and so are not tabulated or discussed here.

3. The Sport Fish and Sport Fishery

Apparently the California Department of Fish and Game cannot abide a body of water which lacks a viable sport fishery: "The vast expanse of the Salton Sea has long presented a challenge to the California Department of Fish and Game,

but a lack of funds and manpower precluded any concerted attempt to establish game fish there until 1950" (Anonymous 1958). Fish and Game has introduced to nearly all California waters many alien species, including centrarchids, salmonids, and other fish from elsewhere in the US and the world, as well as California fish not native to that particular geographical area (Swift et al. 1993; Dill and Cordone 1997). The Salton Sea has been no exception. Fish and Game has at least three times made major attempts to introduce sport fish to the Sea; the first and second in the early 1930s were both failures. The third attempt, in the early 1950s (see below), was spectacularly successful. There are very few species of fish in the Salton Sea, but those are extremely abundant, and within only a few years the Sea supported the most productive sport fishery in the state and probably the US. The Salton Sea State Recreation Area was established in 1955 along the eastern shore to provide camping and other amenities for the rapidly developing sport fishery (Laflin 1995, 1998). In the 1970s Fish and Game created several "fishing reefs," three of them piles of tires chained together ~1000 meters offshore, and others made of car bodies (Stroud and Jenkins 1960; *Los Angeles Times* 29 March 1974). Artificial reefs, as well as drowned structures such as buildings and utility poles, concentrate fish, making these areas particularly attractive for fishers.

When the Salton Sea formed in 1905 to 1907, it was initially populated by freshwater fishes native or introduced to the Colorado River (Grinnell 1908; Evermann 1916; Coleman 1929; B. W. Walker et al. 1961a; Dill and Cordone 1997), although no complete survey was ever done. In 1916, the major Salton Sea fish (see Table VIII for scientific names) were all freshwater except for the migratory mullet: carp (introduced), striped mullet, humpback or razorback sucker, rainbow trout, bonytail, and desert pupfish (Evermann 1916). By 1925, when the Salton Sea reached its lowest elevation and highest salinity through evaporation, all freshwater sports fish except striped mullet and the migratory, euryhaline tenpounder or machete, *Elops affinis* (Elopidae), had died out. *Elops,* survived in the Salton Sea longer than most Colorado River fishes, supporting a modest sport fishery into the 1930s (Dill and Woodhill 1942; Swift et al. 1993; Dill and Cordone 1997). There was a "fabulous" commercial fishery for mullet beginning with the formation of the Salton Sea in 1907. Mullet as large as 9.5 kg were taken, and in 1918 a total of 41,370 kg were landed. Mullet made "huge" spawning runs up the New and Alamo rivers as late as the 1950s (Costa-Pierce 1998a). Mullet are still present in small numbers (see below), but *Elops* has been believed extinct in California. However, recent reports indicate that *Elops* still occurs in the lower Colorado River, apparently as a consequence of several years of high river flow that connected the river to the Gulf of California (Bettaso and Young 1999).

In 1929 and 1930, the California Department of Fish and Game attempted to introduce to the Salton Sea euryhaline striped bass (*Morone saxatilis,* Serranidae, native to the US East Coast but widely introduced elsewhere, including San Francisco Bay). In support of this attempt to create a sport fishery, in the late 1920s Game Warden Glidden tried to establish food sources for the striped bass, buying bucketsful of live bait in San Diego which he dumped into the Salton Sea. Introductions of striped bass in 1929 (from the San Joaquin River) and 1930 (from

San Francisco Bay) did not succeed, but it is generally believed that the introductions of the pileworm *Nereis succinea* and the longjaw mudsucker *Gillichthys mirabilis* date to Warden Glidden's bait purchases in 1929 (Anonymous 1929, 1930a,b, 1931a,b, 1932, 1958; B. W. Walker et al. 1961a).

In 1934, Fish and Game introduced 15,000 fingerlings of the Pacific northwest silver (coho) salmon (*Oncorhynchus kisutch,* Salmonidae), from a hatchery in the San Bernardino Mountains. None were ever seen again (B. W. Walker et al. 1961a; de Stanley 1976).

The third, and most serious, attempt by Fish and Game to create a sport fishery came in the early 1950s. Fish and Game personnel selected as their source the San Felipe area of the northern Gulf of California, and in scattershot fashion introduced small numbers of 30 different fish species as well as a number of marine invertebrates—the only selection used was to eliminate species they thought might be detrimental in the Salton Sea (B. W. Walker 1961; Dill and Cordone 1997). de Stanley (1976) published several photographs of the transplant operation. None of the invertebrates from this introduction survived. Of the 30 species of fish, only three were successful colonizers of the Salton Sea: bairdiella, sargo, and orangemouth corvina (the top carnivore in the Sea though nothing remarkable in the Gulf). Within a few years of their introductions, these three species made the Salton Sea the most popular sport fishery in the state, with >1.5 million use-days per year. It was also the most productive fishery: from the 1960s through 1980s; fishers caught an average of 1.46 fish per hour (Black et al. 1985). Tilapia, introduced in the 1960s, made up the largest share of this fishery in more recent years (41%), with bairdiella and sargo next (both 28% of the total). Orangemouth corvina account for only 3.5% of the total, because they are caught primarily from boats rather than from shore (Black et al. 1985). This fine sport fishery requires no hatcheries and is fully self-sustaining. With up to 2.6 million recreation days per year in the late 1980s, sport fishers brought in as much as $76 million to the local economy, the equivalent of over 1400 jobs in Riverside and Imperial Counties (CIC Research Inc. 1989).

Popular accounts of the sport fishes, how to catch them, and how to prepare them for eating have been published by St. Amant et al. (1978), Jansen et al. (1985), and Karr (1985). Karr (1985) made numerous errors on the history and biology of the Salton Sea itself, as did some of the expert orangemouth corvina fishers interviewed by Jansen et al. (1985). Curiously, some federal agencies deny the fact of the fine sport fishery, e.g. "The sport fishery at Salton Sea is nonexistent today" (US Fish and Wildlife Service, 1997b). The Salton Sea Authority and US Bureau of Reclamation (2000a) concluded, to its apparent surprise, that the sport fishery was extraordinarily productive. Orangemouth corvina and tilapia are described both as growing faster and having shorter life spans in the Salton Sea than in their native waters. There is no elevated frequency of deformed fishes (Costa-Pierce et al. 2000). In other words, the sport fishery in 1999 to 2000 is in fine shape. In the following discussion, histories of introductions come from several chapters in B. W. Walker (1961), summarized by Dill and Cordone (1997).

The Salton Sea population of the Gulf croaker or bairdiella, *Bairdiella icistia* (Sciaenidae), derives from introductions of only 67 individual fish (57 in 1950, 10 in 1951). Salton Sea bairdiella first spawned in 1952; there was explosive population growth in the presence of the great pileworm food supply. Their pop-

ulation reached as high as ~10 million fish standing crop in the Sea within a few years, and now it is the second most abundant sport fish in the Sea, after tilapia. Despite the small inoculum, bairdiella genetic diversity is high; there is no evidence for a founder effect or a genetic bottleneck (Beckwith 1987).

Bairdiella are panfish up to 30 cm long, found everywhere in the Sea; they occur occasionally in shoreline pools (Barlow 1958a). They spawn from May to June; eggs float near the surface where early development also takes place (Haydock 1971). Very young bairdiella are zooplanktivores; juveniles and adults feed primarily on benthic pileworms (a detailed discussion of bairdiella food is given by Quast 1961). Bairdiella serve as a major food for adult orangemouth corvina and perhaps tilapia. There is some invasion of the lower reaches of streams such as the Whitewater River (Whitney 1961a; Swift et al. 1993). At the Salton Sea bairdiella live up to 8 years. Bairdiella often have massive summer die-offs from low O_2 concentration and consequent reduced pileworm food supply, with up to 3 million deaths within a couple of months. These die-offs began within a few years of their introduction. Whitney (1961b) concluded that in the summer, when bairdiella are food-limited by the great reduction in pileworm density and distribution, they may compete strongly with juvenile orangemouth corvina, which also feed almost exclusively on pileworms (Quast 1961; Whitney 1961a; May 1975b, 1976; Riedel and Costa-Pierce 2000).

Growth of adult bairdiella is depressed at 45 g l^{-1}, and adults die at 75 g l^{-1}. Bairdiella hatching was successful at Salton Sea salinities of 35 g l^{-1} (84% hatch success) but declined at higher salinities. In 45 g l^{-1} only 7% hatch, the survivors dying within 60 hours. Fingerlings were more resistant, with 100% survival in 52.5 g l^{-1} (US Department of the Interior and The Resources Agency of California 1969; Hanson 1970; Brocksen and Cole 1972; Lasker et al. 1972; May 1974a, 1975a,b; Black 1981). Hanson (1970), Brocksen and Cole (1972), and Lasker et al. (1972) concluded that 40 g l^{-1} exceeds the upper limit for successful bairdiella reproduction, but did not rule out higher limits after slow adaptation to higher salinities—an ecologically and physiologically reasonable scenario—or reproduction in lower salinity waters near the mouths of rivers and larger drains. In 2000 Bairdiella fishing remained excellent, particularly by children; clearly, adequate reproduction and survival occur at 43 to 47 g l^{-1}.

Matsui et al. (1991a) studied ichthyoplankton in the Salton Sea in 1987 to 1989, finding that the abundance of bairdiella larvae increased in each of three years; conversely, the abundance of sargo and orangemouth corvina larvae declined. Whitney (1961a) documented a number of developmental deformities in bairdiella in the 1950s, but did not identify any causes. Matsui et al. (1992) also found developmental defects in both field populations and laboratory-reared scaienids (bairdiella, orangemouth corvina) in the 1990s. In neither case were any studies done to determine if mortalities had any significant effects on sciaenid population biology. Costa-Pierce et al. (2000) reported no deformities in adult sport fishes caught in the Sea.

The large Salton Sea population of sargo, *Anisotremus davidsoni* (Pomadysidae), is derived from an introduction in 1951 of just 65 fish; there was no early explosive population growth as with bairdiella. There was a standing crop of ~5 million sargo in the Sea in the late 1990s, but it was the least abundant of the four sport fishes (Riedel and Costa-Pierce 2000). Sargo commonly reach >1 kg

and >35 cm in length; the state record in the 1970s was 1.9 kg (de Stanley 1976). Sargo are particularly abundant near the shoreline and submerged structures (Department of Fish and Game undated handout). Little is known about reproduction, but spawning occurs in winter and spring. Sargo rarely live more than 3 yr (Riedel and Costa-Pierce 2000). Summer die-offs are not as intensive as with bairdiella. Sargo are an important sport fish ("a tasty dish": de Stanley 1976), feeding on benthic invertebrates (Walker et al. 1961b; Riedel and Costa-Pierce 2000). Sargo did not figure prominently in the excellent sport fishery in 1999 and 2000.

Studies on effects of salinity on sargo development gave results similar to those for bairdiella, with 90% hatching success in 35 g l^{-1} but only 8% success in 40 g l^{-1} and no success in 45 g l^{-1}; fingerlings were somewhat more sensitive to higher salinities than were those of bairdiella. Growth of sargo adults is hampered at 45 g l^{-1}, and adults die at 62.5 g l^{-1} (US Department of the Interior and The Resources Agency of California 1969; Hanson 1970; Brocksen and Cole 1972; Lasker et al. 1972; Black 1981; Matsui et al. 1991b). The sex ratio is approximately even (Riedel and Costa-Pierce 2000). Lasker et al. (1972) concluded that 40 g l^{-1} exceeds the upper limit for successful sargo reproduction, but did not rule out either higher limits after gradual adaptation to higher salinities or reproduction in lower salinity waters associated with agricultural inflow.

The orangemouth corvina, *Cynoscion xanthulus* (Sciaenidae), is the premier sport fish of the Salton Sea, and thus of California. Salton Sea orangemouth corvina derive from several introductions in 1950 to 1956 of not more than 272 fish. In the 1970s and 1980s their standing crop population was 3 to 5 million fish, with around 0.5 million caught per year. "This fish is a gourmet's delight, for there is no finer tasting fish to be found anywhere, baked, broiled, fried, or smoked" (de Stanley 1976). Limit is 5 per day, reduced from 9 per day several years ago. Orangemouth corvina are schooling, open-water fish. Adult orangemouth corvina are piscivores, feeding on bairdiella, sargo, and tilapia at and near the bottom; fingerlings are zooplanktivores, while juveniles feed on small fish and benthic pileworms. There is some invasion of the estuaries of the Whitewater and Alamo Rivers (Swift et al. 1993), apparently for breeding (Department of Fish and Game undated handout). Orangemouth corvina commonly reach 9 to 11 kg. The larger fish usually caught weigh from 7 to >11 kg. The record orangemouth corvina weighed 16.8 kg (length >1.14 m, girth >0.72 m); it was caught by Dick Van Dam, Jr., on 15 July 1988, near Red Hill—a very impressive fish, estimated to be ~30 yr old (Horvitz 2000). Though this 1988 record has not been topped, orangemouth corvina in the range of 12 to 14 kg and >1 m are still regularly caught. Reports of 18 to 23 kg orangemouth corvina are unconfirmed, and may just represent standard tall tales from fishers (Whitney 1961b; Lasker et al. 1972). A year-long creel census in the early 1980s indicated that the average orangemouth corvina taken from the Salton Sea was ~50 cm long, which is also the size they become sexually mature (Black et al. 1985). Black et al. (1985) expressed concern that "there may be a significant portion of the population being removed before it has an opportunity to spawn," and suggested that a minimum size limit be set. A minimum size limit of 45 cm was set in March 2000 (Oglesby pers. obs.), which is below the size at first reproduction (Whitney 1961b; Black et al. 1985; Prentice and Colura 1984). Orangemouth corvina fishing is best in the summer when the air is beastly and the water warm, but there are good bites

during warm winters as well (e.g., 1999 to 2000: Matthews' Pick of the Week, Ontario CA *Inland Valley Daily Bulletin*).

Salinity resistance studies show that orangemouth corvina fingerlings are more resistant than those of either bairdiella or sargo, with 100% survival at 52.5 g l^{-1}, 91.4% hatch success at 57.5 g l^{-1}, and no survival at 62.5 g l^{-1} (US Department of the Interior and The Resources Agency of California 1969; Hanson 1970; Brocksen and Cole 1972; Prentice 1985; Matsui et al. 1991c). When gradually adapted to freshwater in the laboratory, orangemouth corvina do not feed for the first week or so but afterwards resume normal feeding (Prentice 1985). Freshwater-adapted orangemouth corvina are excitable, and Prentice (1985) attributed their mortality to injury in collisions with the tank and to subsequent fungal infections (*Saprolegnia*), rather than to low salinity itself. Orangemouth corvina exhibit stress when in fresh water, but continue to grow, though at about half the rate of fish maintained in sea water (Prentice 1985). Feeding activity of laboratory orangemouth corvina is "greatly decreased" at temperatures below 18 to 20°C (Prentice and Colura 1984).

Orangemouth corvina breeding is not well understood. A great increase in underwater sound was observed by hydrophone in the deepest part of the northern basin of the Salton Sea in the late spring. This huge increase in sound was attributed to the peak of reproduction by orangemouth corvina (Fish and Cummings 1972). The main breeding season at the Salton Sea is from April to August, with fingerlings still in the plankton in October (Matsui et al. 1991c). Prentice and Colura (1985) exposed a laboratory population of Salton Sea orangemouth corvina to cycles of temperature (varying from 16 to 28°C), salinity (varying from 17 to 33 g l^{-1}), and photoperiod (varying from 15: 9 L:D to 9:15 L:D) "to simulate seasonal variations of the Salton Sea," though salinity does not vary seasonally. Laboratory males became sexually mature at 50 cm, greatly increased their drumming, and could spawn; 60 cm laboratory females developed eggs, but could be induced to spawn only after injection of human chorionic gonadotrophic hormone. No fertilized eggs were obtained. Size at sexual maturity of laboratory populations is consistent with observations at the Salton Sea (Whitney 1961b). Laboratory spawning took place only during simulated summer conditions, somewhat later than Whitney (1961b) observed at the Salton Sea itself, in late May and June. In a later study, Prentice and Thomas (1987) reported successful spawning of orangemouth corvina in response to injection of several hormones, but did not indicate whether there was successful fertilization. Bumguardner et al. (1992) raised large numbers of orangemouth corvina to fingerling size in laboratory ponds. The orangemouth corvina sex ratio favors females in estuaries and males in the open sea, and is approximately equal near shore (Riedel and Costa-Pierce 2000).

The fourth major Salton Sea sport fish is the tilapia, an African cichlid. Tilapia have established an immense breeding population in the Salton Sea and in nearly every canal and ditch as well as in some streams and springs in the Valle de Mexicali, Imperial Valley, and Coachella Valley.

There has been much confusion as to which species of tilapia is (are) in the Salton Sea and canals and drains in the Coachella and Imperial Valleys. Fortunately, these taxonomic problems have been sorted out (Costa-Pierce and Doyle 1997; Costa-Pierce 1998a,b; Costa-Pierce and Riedel 2000; Riedel and Costa-

Pierce 2000), though not all current workers are aware of these changes and may still use old names or even names of species never found in California. All tilapias are native to Africa, but have been widely introduced for aquaculture and other purposes around the world, arriving in California up to fourth-hand. Both Salton Trough tilapia species were introduced from countries outside of Africa (Table VIII). Members of the genus *Tilapia* are nest brooders while *Oreochromis* are female mouth brooders. While *Tilapia zillii* is readily separated from members of the genus *Oreochromis* by external morphological criteria, such criteria cannot be used successfully within *Oreochromis.* (Costa-Pierce and Doyle 1997; Costa-Pierce 1998a,b; Costa-Pierce and Riedel 2000; Riedel and Costa-Pierce 2000).

Tilapia zillii was the species name most often mentioned after tilapia first entered the Salton Sea, but this species has not been recovered recently from the Salton Sea itself, though it is still present in adjacent wetlands. *T. zillii* (Zill's or redbelly tilapia) was introduced into Imperial Valley drains in 1971 in an ill-advised attempt to control aquatic weeds (Costa-Pierce 1998a,b; Costa-Pierce and Doyle 1997). *T. zillii* is much more euryhaline, eurythermal, euryoxic, and euryphagic than originally believed on the basis of inadequate experimentation by a biologist for the Imperial Irrigation District (Hauser 1975a,b, 1977; Hauser and Legner 1975). Costa-Pierce and others recommend total eradication of *T. zillii,* finding it worthless for any useful purpose (aquatic weed control, aquaculture, fishing), despite its euryplastic physiology and rapid growth rate (Costa-Pierce and Doyle 1997; Costa-Pierce 1998a,b; Costa-Pierce and Riedel 2000; Riedel and Costa-Pierce 2000).

The only known tilapia species in the Salton Sea itself is *Oreochromis mossambicus* (Mozambique tilapia). It was introduced into the lower Colorado River near Yuma in 1964, and reached the Imperial Valley and Salton Sea a year later, by as many as three routes: an illegal aquarium route from a fish farm near Niland, invasion from Arizona irrigation canals by way of the Colorado River and Imperial Valley canals, and deliberate stocking (St. Amant 1966; Hoover and St. Amant 1970; Hoover 1971; Costa-Pierce and Doyle 1997; Costa-Pierce 1998a,b; Costa-Pierce and Riedel 2000). Genetic analysis of Salton Sea tilapia, using microsatellite DNA marker frequencies, shows considerable differentiation from "pure" African *O. mossambicus,* and some genetic inflow from *O. urolepis hornorum* (Wami River tilapia), even though the latter is not present in California; the California strain of Mozambique tilapia is clearly not pure *O. mossambicus.* It also has the highest heterozygosity of any tested California tilapiine strain, about the same as reference collections from Africa, indicating great genetic diversity. Along with carp (*Cyprinus carpio*), *O. mossambicus* is the most widely introduced exotic fish in the world, although it is generally regarded as not as valuable for aquaculture as *O. niloticus* (Costa-Pierce 1998a; Costa-Pierce and Doyle 1997). No genetic programs have been conducted to improve *O. mossambicus* for aquaculture; but Costa-Pierce (1998b) concluded that it is premature to write this species off in favor of *O. niloticus.*

Other species of *Oreochromis,*—the first two currently illegal in California— *O. aureus* (blue or golden tilapia), *O. niloticus* (Nile tilapia), and *O. urolepis hornorum* (Wami River tilapia) do not seem to be feral in the Salton Trough (Costa-Pierce and Doyle 1997; Costa-Pierce 1998a,b; Costa-Pierce and Riedel

2000, Riedel and Costa-Pierce 2000). *O. niloticus* is present in the Colorado River near Blythe and thus has the ready potential of invading the Salton Trough; it is also permitted in at least one aquaculture operation in Southern California outside the Trough (Costa-Pierce and Doyle 1997). *O. niloticus* grows faster, has a larger size at first reproduction, and is more herbivorous than other tilapia species. *O. urolepis hornorum* is notable for the male-only progeny of hybrids of male *O. urolepis hornorum* with female *O. mossambicus. O. urolepis hornorum* apparently has never been imported to California (Costa-Pierce 1998a,b).

Both Salton Trough tilapia species are not just herbivores as originally believed; they are broad-spectrum omnivores that readily feed on all types of small organic particles, aquatic plants, small invertebrates (especially insects, crustaceans, and pileworms), and small fish including desert pupfish. Juvenile tilapia are more euryphagic than adults (Moyle 1976; Hart et al. 1998). The population of desert pupfish in the Salton Sea, canals, and drains has crashed, but only since introduction of tilapia; Costa-Pierce and Riedel (2000) attributed this great population reduction of desert pupfish specifically to *Tilapia zillii,* since desert pupfish share waters with *Oreochromis mossambicus.*

Tilapia are strongly euryhaline, swimming readily from the Salton Sea across the horohalinicum into drains and rivers and back again. Salton Sea tilapia tolerate salinities from freshwater to at least 70 g l^{-1}; *T. zillii* handles direct transfer from freshwater to 35 g l^{-1} seawater (Potts et al. 1967; Hammer 1986) while *O. mossambicus* needs a more gradual acclimation to extreme salinities (Costa-Pierce and Riedel 2000). Tilapia reproduce at salinities as high as 60 g l^{-1}, though not at 79 g l^{-1} (Kültz and Onken 1993; Hart et al. 1998; Costa-Pierce and Doyle 1997; Costa-Pierce 1998b; Costa-Pierce and Riedel 2000; Riedel and Costa-Pierce 2000). Both tilapia species are reported as living elsewhere in salinities as high as 74.9 to 134.4 g l^{-1}, but not reproducing at salinities higher than 63.6 g l^{-1}. When adapted to a range of salinities from freshwater to seawater, *O. mossambicus* shows adaptive changes in numbers and morphology of chloride cells, changes in chloride cell permeability, and changes in whole-body permeability (Kültz and Onken 1993; Bijvelds et al. 1997; Miyazaki et al. 1998; Vonck et al. 1998; Hiroi et al. 1999; Uchida et al. 2000). There is evidence that at high salinities, tilapia have increased sensitivity to organic pollutants (Salton Sea Authority and US Bureau of Reclamation 2000a).

Tilapia zillii will die at temperatures <7°C. The lower limit for the more stenothermal *O. mossambicus* seems to be ~10 to 15°C. Cold stress sets in at ~15°C, with lethal temperatures ~5.5 to 12°C. Winter tilapia kills at the Salton Sea are likely caused by low temperatures, both from the low temperature itself and perhaps from stress-induced greater sensitivity to pathogens. *O. mossambicus* can tolerate water as warm as 40°C, but grows optimally at 25 to 37°C (Costa-Pierce and Doyle 1997; Costa-Pierce and Riedel 2000). Developing *O. mossambicus* have deformities when raised at elevated temperatures of 28 and 32°C; since summer temperatures at the Salton Sea are warmer than 32°C, one might expect a proportion of deformed fish, but none have been reported. Low temperatures lead to feminization (Wang and Tsai 2000); in the Salton Sea, the sex ratio of *O. mossambicus* is strongly skewed toward males, as much as 7:1. Tilapia are now an important food for adult orangemouth corvina (Hauser 1975a,b, 1977; Moyle 1976; Knaggs 1977; Schoenherr 1981).

Tilapia zillii breeds year-round whenever temperatures exceed 15°C. Female *T. zillii* lay their eggs in small nest depressions made by males in shallow water; one or both *T. zillii* parents guard the nest until the eggs hatch. *Oreochromis mossambicus* females brood up to 400 eggs in their mouths. A side-scan sonar image of the 1946 wrecked Grumman Avenger on the sea bottom at a depth of ~16 m showed a striking and dense pattern of apparent pits ~0.7 to 1 m across surrounding the downed plane, but these features were not commented upon (*Los Angeles Times,* 15 June 1999). Both B. Costa-Pierce (pers. comm.) and S. Hurlbert (pers. comm.) thought these pits were tilapia nests, in which case there must still be a species of the benthic-brooding genus *Tilapia* present in the Salton Sea. Tilapia, particularly *O. mossambicus,* can breed at 90 d from hatching and every 60 d thereafter (Karr 1985) or at 60 d from hatching and every 35 d thereafter (Jansen et al. 1985), and so have an immense potential for rapid population growth, even after a major die-off.

Year-round, *Oreochromis mossambicus* is most common near the shoreline and in estuarine areas offshore from the mouths of the New and Alamo Rivers. This distribution makes them easily caught by shoreline fishers. Shoreline tilapia are more concentrated near the bottom during the summer, and occupy the entire water column in winter; open Sea *O. mossambicus* rarely are caught near the bottom at any time (Costa-Pierce and Riedel 2000). Mozambique tilapia do not colonize the two rivers much, perhaps because of their high silt loads and rapid currents (Costa-Pierce and Riedel 2000). The Salton Sea produces as much as 3600 kg tilapia ha^{-1} yr^{-1}, as much as three to four times higher than in several locations in the Philippines and Sri Lanka cited by Costa-Pierce and Riedel (2000). Most of the tilapia caught in the Salton Sea in 1999 were 1 yr old, younger than at most other locations in the world.

Costa-Pierce and Riedel (2000), Riedel and Costa-Pierce (2000), and Salton Sea Authority and US Bureau of Reclamation (2000a) proposed a commercial harvest for Salton Sea tilapia, taking older fish and permitting younger fish to grow faster, thus increasing the overall productivity of the fishery while reducing Sea PO_4^{3-} and thus hypereutrophication. This approach is likely to be futile, based as it is on unsupported assumptions and inadequate science (see above).

Costa-Pierce and Doyle (1997) warned against using Salton Sea tilapia as sources for aquaculture broodstock because of the likelihood of disease, and also warned against importation of any tilapia from elsewhere until it is known for sure that they would not transmit the pathogenic bacterium *Streptococcus,* which could cause severe disease both in aquaculture ponds and in the Salton Sea. However, *Streptococcus* is already known from Salton Sea *O. mossambicus* (Costa-Pierce 1998b). Newly imported tilapia species or even different stocks of the species already present might adversely impact the Salton Sea's unusual fish community and its productive fishery.

Salton Sea tilapia are subject to sometimes immense die-offs, apparently from low water temperature in the winter and from low O_2 concentration and high H_2S concentration after wind-caused summer breakdowns of thermal stratification (see below). Nevertheless, the tilapia standing crop has been estimated as high as 100 million in the Sea. Tilapia have become the most popular sport fish of the Salton Sea, reaching ~2 kg and 40 cm; they are easily caught from shore using simple baits (Oglesby pers. obs).

Some 40 aquaculture facilities in both the Imperial and Coachella Valleys raise tilapia (chiefly *Oreochromis mossambicus*). Immensely popular in Asian, Mexican, and Puerto Rican communities, tilapia recipes are increasingly presented to mainstream fish cooks by magazines and newspapers (*Sunset* Mag. May 1991: 162, 164). Salton Trough tilapia aquaculture produces ~13 million kilograms per year (kg yr^{-1}), ~40% of national production. Fish are ready for market at 8 months when they have reached an average weight of 570 g (Costa-Pierce, 1998b). About 11,000 to 15,400 kg are shipped live each week for sale to markets in Los Angeles and San Francisco. Salton Trough tilapia production increased 8% from 1997 to 1998, and is expected to continue to increase (Costa-Pierce and Riedel 2000). California is the largest domestic producer of tilapia. Even so, more tilapia are imported (28.2 million kg in 1996) than are produced in US aquaculture, and imports are still rising (Costa-Pierce and Doyle 1997).

Other organisms grown in Salton Trough aquaculture facilities include tropical fish for home aquarists, several species of catfish (Ictaluridae), largemouth bass (*Micropterus salmoides*), hybrid striped bass, rainbow trout (*Oncorhynchus mykiss,* Salmonidae), "shrimp," and several groups of algae such as the halophile red chlorophyte *Dunaliella* and the cyanobacterium *Spirulina.* Many of these aquaculture facilities, particularly in the Coachella Valley near the mouth of the Whitewater River, are also used as migratory duck hunting clubs in the winter. The Imperial Irrigation District is beginning to use duck hunting ponds in its projects to increase the acreage of wetlands in the Salton Trough, maintaining them with water during the summer rather than letting them be drained, reducing inflows to the Salton Sea by ~8,400 acre-feet yr^{-1} (Imperial Irrigation District Public Information Office 1998a).

Rumors persist about the presence in the Salton Sea of one or a few giant totoabas (*Totoaba macdonaldi,* Sciaenidae), a splendid fish that can reach ~2 m long and >60 kg, that was supposedly introduced in the 1950s from the Gulf of California where the species is now seriously endangered (Mellink and Ferreira-Bartrina 2000). There is no evidence to support this.

The native, cosmopolitan euryhaline striped (or gray) mullet, *Mugil cephalus* (Mugilidae), migrated into the Salton Sea from the Gulf of California after the Sea's formation in 1905 to 1907. Reaching 4.5 to 5.5 kg, mullet were the only fish legally taken from the Salton Sea by commercial interests, first in 1915 to 1921, reaching a peak landing of 41,370 kg in 1918, and then again from 1942 to 1953, when commercial fishing was banned to protect the newly introduced sport fish. By then, mullet catches were too low to sustain commercial exploitation. The history of commercial mullet fishing in the Salton Sea was described by Thompson and Bryant (1920), Dill and Cordone (1997), and Costa-Pierce (1998a). Catadromous adults spawning in the Gulf of California migrated to the Salton Sea by way of the Colorado River and irrigation canals, but there is no evidence they ever spawned in the Sea, despite its salinity which was then about the same as the ocean. When permanent headgates for the All-American Canal were established in 1942 above the 7 m high Imperial Dam upstream from Yuma, migration of striped mullet from the Gulf of California was blocked. Mullet seen in the Salton Sea since that year presumably are descended from those who left the Gulf of California prior to 1942. Several mullet were taken by fishers in the late 1990s (Horvitz 2000). Bettaso and Young (1999) noted that young mullet

had been found in the Colorado River as far as 193 km from the Gulf of California, and speculate that there may be some freshwater spawning of the species.

Mullet filter-feed on plankton to a small extent but feed primarily on benthic algae, particularly diatoms (Hendricks 1961b; B. W. Walker et al. 1961a; Moyle 1976; Eggold and Motta 1992; Cardona et al. 1996). Mullet are euryhaline, adaptively changing the number and activity of gill chloride cells and Na^{1+}-K^{1+} ATPase in response to salinity (Murashige et al. 1991; Ciccotti et al. 1995; Hotos and Vlahos 1998).

See Table VIII for a list of fish of the Salton Trough, a table that is probably incomplete for "freshwater" fish. Table 25 in B. W. Walker et al. (1961a), Table 2 in Dill and Cordone (1997), and Table 1 in Costa-Pierce (1998a) list the many known fish introductions into the Salton Sea up to the late 1950s; nearly all have been failures. These lists were expanded by Swift et al. (1993). Introductions of other fish species probably take place frequently, when people bring live bait to the Salton Sea or dump their aquaria.

The various studies discussed above indicate that reproduction of Salton Sea sport fish, especially sargo and bairdiella, is likely to be seriously diminished when salinities reach 40 to 45 g l^{-1}, a concentration which was exceeded by the late 1990s. But even if the major part of the Salton Sea exceeds 40 to 45 g l^{-1} during the entire year, there might still be adequate reproduction by fish migrating into lower salinity estuarine areas near the mouths of the Alamo, New, and Whitewater Rivers and larger drains. There is some indication that orangemouth corvina now breed preferentially near the New and Alamo river mouths. Developmental stages of all these species are more sensitive to higher salinities than are adults; thus, lower-salinity estuarine habitats might serve as nurseries, with fish dispersing into the Sea once they reach a more high-salinity tolerant subadult or adult stage. There was no diminishing of the sport fish catch in 1999 and 2000.

A problem of unknown magnitude beginning in the 1980s is illegal fishing for orangemouth corvina and tilapia, conducted primarily by southeast Asian immigrants using gill nets. For example, in 1983, 18 people were charged with gill netting 3200 kg tilapia (≈2250 fish); California Department of Fish and Game personnel said the fish were to be sold live in markets in San Diego, Orange, and Los Angeles Counties. "Our information is that some people have made as much as $9000 on a single weekend by selling fish illegally taken from the Salton Sea," said Warden Laret in November 1982. In another example, in 1988 two men were seriously injured when their car caught fire on State Highway 86 in the Salton Sea State Recreation Area, flipped over, and spilled 136 kg (≈30 fish, ~12 over the then-limit of nine fish per person) of orangemouth corvina onto the road. The Department of Fish and Game is attempting to educate the Southeast Asian immigrant community in southern California about California fishing law and the importance of conservation, as traditional fishing procedures used in the former Indo-China are illegal in California. The paucity of reports of illegal fishing in the Salton Sea in the 1990s may reflect a genuine reduction in poaching, or just reductions in State funding for Department of Fish and Game surveillance and enforcement (information from news articles in the Pomona CA *Progress Bulletin* and *Los Angeles Times*).

As of 2000 the Salton Sea still maintains a superb sport fishery, even if many fishers have deserted it because of unfounded rumors. Jim Matthews, outdoors

columnist for the Ontario CA *Inland Valley Daily Bulletin*), wrote on 3 June 1999: "Where would you go fishing this weekend? My first pick is the Salton Sea. It is easily the most productive fishery in the nation, producing more fish per surface acre than—well—anywhere. This is the place to take the kids and truly catch a mess of fish. If you fish with nightcrawler pieces from shore, you will catch dozens—no, hundreds—of tilapia and bairdiella. Fish from a boat, float tube, or wade out to your armpits and make long casts, and you will catch corvina to [2.7 or 3.6 kg] on mudsuckers. All three species are great eating."

4. Other Fish

Planktivorous fish.—The euryhaline and migratory threadfin shad (*Dorosoma petenense,* Clupeidae) is the only planktivorous fish in the Sea. *D. petenense* is an obligate planktivore, filter-feeding on both phyto- and zooplankton. These fish are not very important in the Salton Sea ecosystem though they are readily fed upon by carnivorous fish (Devries et al. 1991; Garvey et al. 1998). They are of some seasonal importance as food for Salton Sea orangemouth corvina. Threadfin shad were introduced from the Tennessee River in 1954 "on the optimistic assumption that they were the ideal forage fish for California reservoirs and should greatly improve growth rates of game fishes" (Moyle 1976). Threadfin shad entered the Salton Sea in 1955, only 8 months after introduction of just 1020 fish into Lake Havasu behind Parker Dam on the Colorado River. The Salton Sea threadfin shad migrate back into the Colorado River to breed. Threadfin shad are most abundant along the eastern shoreline, particularly near freshwater inlets; both the New and Alamo Rivers harbor small populations (Costa-Pierce et al. 2000). Native habitat for threadfin shad is streams entering the Gulf of Mexico from the US south to Belize (Hendricks 1961a; B. W. Walker et al. 1961a; Moyle 1976; Dill and Cordone 1997).

Non-planktivorous fish.—Of the remaining species of fish in the Salton Sea (Table VIII), the one of greatest interest is the desert pupfish, *Cyprinodon macularius* (Cyprinodontidae). The only native fish now present in the Salton Sea, *C. macularius* initially colonized the present Salton Sea as its waters rose over desert springs, streams, and oases from 1905 to 1907. Desert pupfish were formerly abundant along the shoreline of the Salton Sea, in shoreline pools, in freshwater springs, in streams such as Whitefield Creek, and in drains, as well as in drainages leading to the lower Colorado River. B. W. Walker et al. (1961a) wrote, "Pupfish are everywhere about the shores of the Salton Sea where there is quiet water," a statement that unfortunately is no longer true.

The introduction of competitors and predators, especially sailfin mollies, mosquitofish, tilapia, and bullfrogs, has led to a precipitous decline in desert pupfish abundance everywhere in the Salton Trough in the past 30 yr. Black (1980) estimated that the ratio of predators and competitors to desert pupfish in drains and shoreline pools varied from 2:1 to as high as 188:1. Desert pupfish were formerly abundant in springs, notably Fish Springs (now capped) near Desert Shores, but became extinct in all springs by the 1970s. *C. macularius* was placed on both federal and state Lists of Endangered Species in 1986.

For a number of years, the only known significant natural *Cyprinodon macularius* habitat was 23 km^2 San Sebastian Marsh at the confluence of San Felipe,

Fish, Carrizo, and Coyote Creeks (Black 1980; Lebo et al. 1982; Lindsay 2001). San Sebastian Marsh was designated a National Natural Landmark in 1971 by the US National Park Service and as an Area of Critical Environmental Concern and an Outstanding Natural Area in 1975 by the US Bureau of Land Management. About 18 km of San Felipe Creek were designated as critical habitat for desert pupfish by the US Fish and Wildlife Service, together with a 34 m wide riparian buffer zone (US Bureau of Land Management 1986, 1988a). The Bureau has now banned off-road vehicles from the vicinity of the marsh and has done some habitat enhancement for desert pupfish (US Bureau of Land Management *Newsbeat* April 1989). Bullfrogs and tilapia are both present in San Felipe Creek and have been recorded from San Sebastian Marsh. The Bureau proposed a fish barrier on San Felipe Creek downstream from the marsh to prevent upstream migration of tilapia (US Bureau of Land Management 1988a), though tilapia were already present in the marsh and the barrier would not affect bullfrogs.

A population of *Cyprinodon macularius* in México's Ciénega de Santa Clara (Santa Clara Slough) (Fig. 5) in the degraded delta of the Colorado River derives from a 1976 introduction of fish from a refugium at the Boyce Thompson Arboretum, Superior AZ (Fradkin 1981; Turner 1983; Schoenherr 1993b; Zengel and Glenn 1996). The Ciénega is a severely degraded wetland fed only by saline waste US irrigation water ($\sim$144,000 acre-feet yr^{-1}, 3 to 5 g l^{-1}) diverted to the Wellton-Mohawk Drain from agriculture in the Gila River valley in southern Arizona (Fig. 5). Rinne and Guenther (1979) and Mellink and Ferreira-Bartrina (2000) wrote that the Ciénega's desert pupfish population was thriving, but worried that at least nine species of exotic fish had entered the Ciénega through the Bypass Drain from the Wellton-Mohawk Drain, any or all of which could prove to be competitors and predators.

More recently it has become recognized that *Cyprinodon macularius* is much more widespread in the Salton Trough than usually believed, though never abundant. Desert pupfish, along with sailfin mollies and tilapia, were collected in the Whitewater River near its mouth (Feldmeth 1980), presumably from a natural population. Native desert pupfish populations are now known in upper Salt Creek and Oasis Springs Ecological Reserve south of Bat Caves Buttes (Black 1980; Schoenherr 1988; Schoenherr and Feldmeth 1993). It is presumed that desert pupfish provided the name for Fish Creek (one of the tributaries of San Sebastian Marsh), but there have been no fish of any species in Fish Creek since at least the violent floods of 1916 (Lindsay 2001). Managed demonstration populations of desert pupfish are maintained at Salton Sea State Recreation Area, Anza-Borrego Desert State Park, and the Living Desert Reserve in Palm Desert (Black 1980; Schoenherr 1988; Lindsay 2001; Oglesby pers. obs.). The Nature Conservancy restored desert pupfish to Dos Palmas and Thousand Palms Oases, but since both tilapia and bullfrogs are also present in these springs, their desert pupfish populations are not secure. Desert pupfish are present in at least several drains in both the Imperial and Coachella Valleys (Department of Fish and Game; Lau and Boehm 1991; A. Schoenherr pers. comm.; Oglesby pers. obs.). In recent years small desert pupfish populations have been found in the concrete-lined Cleveland Street Spillway near North Shore and in Whitefield Creek in the Salton Sea State Recreation Area (Oglesby pers. obs.). *C. macularius* is widely distributed in northern Sonora and the Colorado Delta in México as well as in southern Arizona

(Hendrickson and Romero 1989). How many of these populations were of *C. eremus* (then called a subspecies of *C. macularius*, see below) was not stated. Populations, with one exception, were low as desert pupfish coexisted with both predators and competitors. The exception was at Cerro Prieto, in a pond with an unusual chemical composition that excluded other fish: desert pupfish were abundant (Hendrickson and Romero 1989).

Reasons why so many species of desert fishes are endangered include: often highly restricted distribution (for many species, just a single spring), damage to riparian habitats by cattle overgrazing and tree cutting, habitat damage from groundwater pumping, surface water diversions for agriculture, drainage of springs, channelization of streams, introduction of competitor and predator fish and other vertebrates, and vandalism (Williams et al. 1985).

Turner (1983, 1984) studied allozyme variation in four natural populations of *Cyprinodon macularius* from the Salton Trough, comparing them with each other and with allozyme patterns of the same subspecies from the Ciénega de Santa Clara and *C. eremus* from Quitobaquito Spring in southern Arizona (recently elevated to separate species status: Echelle et al. 2000) and the nearby Río Sonoyta in Arizona and Sonora, México; he also studied *C. macularius* from four artificial refugia. He concluded that genetic divergence of different populations "has almost certainly been overestimated," and that refugium populations differed little from wild populations. Turner (1984) also concluded that these several natural and refugium populations did not go through any significant genetic bottlenecks and that genetic drift has not been an important process affecting desert pupfish populations. Dunham and Minckley (1998) expressed concern that the limited genetic differentiation of both natural and refugium populations of *C. macularius* would make full recovery to healthy populations difficult.

Desert pupfish are small and chunky, adults no greater than 3 to 6 cm long. Non-breeding *Cyprinodon macularius* form loose schools of similar size for diurnal foraging. They feed unselectively on detritus, algae, and small invertebrates; in the Salton Sea and adjacent waters, prey invertebrates include ostracods, copepods, pileworms, insect larvae (especially chironomids and mosquitoes), and molluscs; they also sometimes eat their own eggs and fry (Moyle 1976; Lebo et al. 1982). Desert pupfish are easily reared in laboratory aquaria over a wide range of salinities and temperatures, permitting detailed studies of their morphological, physiological, and genetic adaptations. Aquarium-raised desert pupfish feed on a variety of readily available foods: *Artemia* larvae, enchytraeid and tubificid oligochaetes, copepods, cladocerans, beef liver, fresh lettuce, spinach, and commercial fish foods (Kinne 1960; Kinne and Kinne 1962; Crear and Haydock 1971).

Few fish can live in such extreme salinity conditions as *Cyprinodon macularius*; adults can live in salinities from freshwater to 68 g l^{-1} while juveniles can withstand up to 90 g l^{-1} (Barlow 1958b; Kinne 1960). Spawning occurs from freshwater to 70 g l^{-1} (Kinne and Kinne 1962). Euryhalinity declines with age, as adults cannot withstand as sudden and extreme salinity transfers as can juveniles (Kinne 1960). Desert pupfish tolerate higher salinities than all other native and introduced freshwater fish, so perhaps as Salton Sea salinity rises, killing less euryhaline fishes, desert pupfish may again become the dominant Salton Sea fish, a situation that Swift et al. (1993) believed has repeated itself many times in the thousands of years of history of desiccating lakes in the Salton Trough.

Schoenherr and Feldmeth (1993) summarized studies on thermal relations of several southwest pupfish species: "Thermal tolerances vary with acclimation temperature and season. Species from constant temperature habitats have narrower ranges of thermal tolerances [than those from thermally variable waters], and those tolerances are inherited." Adult *Cyprinodon macularius* can withstand temperatures from 4.5 to 44.6°C and O_2 concentrations from saturation down to 0.13 mg l^{-1} (Kinne 1960; Sweet and Kinne 1964; Crear and Haydock 1971; Moyle 1976; Black 1980; Schoenherr 1993b Schoenherr and Feldmeth 1993). Kinne (1960) and Sweet and Kinne (1964) documented irreversible phenotypic developmental differences as well as differences in growth rates, food intake, assimilation efficiency, and activity in Salton Sea desert pupfish raised in different but stable combinations of temperature and salinity. In the laboratory, the critical thermal maximum was 44.6°C, the highest known for any teleost fish (Schoenherr and Feldmeth 1993). Desert pupfish avoid the highest temperatures in shoreline pools on hot summer days; if they had cooler temperatures available, they were never observed in waters warmer than 37°C.

Desert pupfish collected in fresh water were frequently infected with an ectoparasitic copepod in the family Lernaeidae. Crear and Haydock (1971) speculated that the parasite was introduced to the Salton Trough from aquarium fish. Infected fish were weak and usually died soon after collection. No lernaeid parasites were found in desert pupfish collected from more saline waters (Crear and Haydock 1971).

Desert pupfish reproductive behavior attracts much attention (Cowles 1934; Barlow 1961; Moyle 1976). Territorial males, blue in their breeding colors, make nests in algal patches in shallow water from mid-spring to late summer. After an elaborate courtship ritual a female is induced to lay one or a few eggs in the nest, which are immediately fertilized; the male then chases away the female. After several females have spawned in a male's nest, he pugnaciously guards the nest until the eggs hatch. In the warm temperatures of their normal habitats, including the Salton Trough, desert pupfish can complete their entire life cycle in one year, but most breed in their second summer (Moyle 1976). Juvenile tilapia can completely disrupt the stereotyped courtship of desert pupfish, curtailing reproduction (Schoenherr 1993b).

Desert pupfish habitat requirements include a sand-silt substrate, abundance of rooted aquatic plants and filamentous algae (not available in the Salton Sea itself), water shallower than 30 cm, minimal surface flow (<0.25 cubic meters per second), and water temperatures above freezing in winter (Black 1980). Desert pupfish living in shoreline pools and streams swim along the Salton Sea shoreline and can colonize adjacent waters (Sutton 2000).

The viviparous mosquitofish *Gambusia affinis* (Poeciliidae), native to the southeastern US, has been widely introduced in the West and elsewhere for mosquito control; it was initially introduced into California in 1922, and mosquito control districts supply large numbers on the slightest demand. Mosquitofish are one of the most common fish in the "minnow" array found in canals and drains, shoreline pools, and calm, shallow areas of the Salton Sea, especially near drain mouths (Barlow 1958a; B. W. Walker et al. 1961a; Oglesby pers. obs.). Moyle (1976) summarized studies on the great thermal tolerance (4 to 37.3°C) of *G. affinis.* Mosquitofish are mostly omnivorous surface feeders (which permits them to live

in hypoxic waters), preying on insects, small crustaceans, and amphibian tadpoles; however, they compete with desert pupfish for food (Black 1980) and may prey on desert pupfish eggs and fry. Desert pupfish would be at least as potent in mosquito control (Kennedy 1916; Moyle 1976).

The Salton Sea population of longjaw mudsuckers, *Gillichthys mirabilis* (Gobiidae), dates from a California Department of Fish and Game introduction of ~500 fish in 1930 from San Diego Bay, in support of the attempt to establish striped bass (Anonymous 1931a, 1958; B. W. Walker et al. 1961a). Longjaw mudsuckers are euryhaline, able to survive being transferred directly from salt water into fresh water, and *vice versa.* Their high salinity limit is 82.5 g l^{-1} (B. W. Walker et al. 1961a; Barlow 1963; Owens et al. 1977). They can grow as long as 14 cm. Longjaw mudsuckers can tolerate fresh water but do not maintain permanent populations there (Moyle 1976).

While widespread in the Salton Sea, longjaw mudsucker distribution is patchy and mostly restricted to quiet shallows and occasionally shoreline pools. Adult longjaw mudsuckers feed primarily on pileworms, other benthic invertebrates, and small fish including desert pupfish. Up to 10% of the diet of younger fish is nematodes. Young fish feed on insects as well. Newly hatched fingerlings are zooplanktivores. Reproduction is in shallow water, from December through June. Females may spawn up to 3 times per year in the Salton Sea. After a stereotyped courtship, a female lays 4000 to 9000 eggs in a burrow in shallow water, guarded by the male until they hatch (Barlow 1958a, 1963; Whitney 1961b; Barlow and De Vlaming 1972; Courtois 1976; Moyle 1976; Loretz 1979; Swift et al. 1993).

Occasionally fed upon by orangemouth corvina, the chief importance of longjaw mudsuckers at the Salton Sea is as orangemouth corvina bait. However, most bait longjaw mudsuckers sold in California, including by Salton Trough bait shops, are trapped from lagoons along the Pacific Coast of Baja California (Dill and Cordone 1997), raising the risk of introduction of undesirable fish species and parasites (see below).

Poecilia latipinna (sailfin molly, Poeciliidae) is a very common conspicuous schooling "minnow" with an iridescent green tail and dorsal fin, but with color variations all the way to rich black; adults reach >12 cm. Introduced ~1964 as escapees from tropical fish farms or released by aquarists who tired of their pets, this euryhaline freshwater fish (native from South Carolina to the Yucatán Peninsula in México) has established huge populations (as much as 20 million fish standing crop) along the shallow margins of the Salton Sea, in drains, and in some larger shoreline pools. Sailfin mollies accounted for as much as 98% of all fish collected in shoreline pools and along the Salton Sea shoreline, and are serious competitors of native desert pupfish (Black 1980). Sailfin mollies live in salinities as high as 87 g l^{-1} and can tolerate up to 92.2 g l^{-1} for several weeks (Nordlie et al. 1992). At the Salton Sea, adult sailfin mollies feed primarily on detritus and bacteria (86% by volume) and algae (14%), rarely invertebrates. Sailfin mollies are livebearers, with Salton Sea fish producing between 20 and 60 young per female; one large female contained 141 embryos (Moyle 1976; Trexler 1985).

Fish in springs, streams, seeps, canals, ditches, and other desert freshwater and athalassic saline habitats.—Collections of fish in drains and canals in the Imperial and Coachella Valleys, waters somewhat saline (2 to 6 g l^{-1} and some-

times higher) due to saline groundwater seepage and agricultural runoff, provide a number of records of introduced fish—cyprinids, centrarchids, ictalurids, and tropical fish "normally" found in domestic aquaria (Table VIII, likely incomplete). It can be expected that breeding populations are or will become established and that ranges of many of these fish will expand. Many are euryhaline and have expanded their ranges to other drains and canals via the Salton Sea (Mearns 1975; Schoenherr 1979; Oglesby pers. obs.). Table VIII lists species known or believed to be inhabitants of canals, drains, and other "fresh" waters of the Imperial and Coachella Valleys; not listed are species now believed to be extinct or at least non-breeding. For more detailed lists and discussions of these fish, see B. W. Walker (1961), Mearns (1975), Moyle (1976), Swift et al. (1993), and Dill and Cordone (1997). Of the species listed in Table VIII, only the desert pupfish and razorback sucker are native to the Salton Trough.

The King Street drain in the Coachella Valley receives both agricultural wastewater at ~22°C and thermal well water at 42°C, producing a strong thermal gradient; O_2 concentration is at or near saturation. Five species of fish (*Cyprinella lutrensis* [as *Notropis*], *Cyprinodon macularius, Gambusia affinis, Poecilia latipinna,* and *P. sphenops*) inhabited the canal before 1976, and displayed different thermal preferences. Desert pupfish inhabited the warmest part of the canal, up to 39°C. Mosquitofish appeared at 32°C, and the remaining three species at 26 to 22°C. There was an almost complete separation of the five species in terms of both thermal and microhabitat preferences (Schoenherr 1979). This result does not really conflict with those of Mearns (1975) for the Johnson Street drain, where a similar array of fish coexisted. The King Street drain was completely remodeled by bulldozer after *chubasco*-caused flooding in 1976, which simplified microhabitats and changed the thermal pattern. The original five species persisted along with newly introduced tilapia, but with reduced niche separation (Schoenherr 1979).

After the failure of introduced tilapia to control aquatic weeds, particularly the rapidly growing—up to 25 cm d^{-1}—Eurasian *Hydrilla verticillata* (Table V), and based on research by its Aquatic Weed Control Facility and fish hatchery near El Centro, the Imperial Irrigation District obtained permission from the California Department of Fish and Game to introduce triploid (sterile) grass carp (*Ctenopharyngodon idella*), originally from east Asia (Imperial Irrigation District Public Relations Office 1998c). Introduced into canals at 0.3 to 0.5 kg, adult grass carp reach 11 to 18 kg and >1 m long. Biologists and engineers with the District regard the experiment as a great success, and note that (unlike tilapia), grass carp do not turn carnivorous when they deplete intra-canal vegetation; rather, they leap out of the water and eat Bermuda grass (*Cynodon dactylon,* Poaceae) growing at the water's edge. Over 200,000 grass carp had been stocked in canals by 1999, ~20,000 to 25,000 per year. Grass carp have established breeding populations in several other river systems in the US, including the Columbia River, the Trinity River in Texas, and the Mississippi River, apparently derived from a few fertile diploid individuals mixed in with stocked sterile triploids (Bain 1993; Raibley et al. 1995; Elder and Murphy 1997; Loch and Bonar 1999). Since grass carp eat plants also fed upon by waterfowl (McKnight and Hepp 1995), care must be taken not to contaminate wildfowl management ponds in the Imperial Valley with this competitive fish.

The original 18,000 triploid grass carp cost $75,000 in 1985 (still cheaper than the $100,000 it costs to clean the canals mechanically), and live a number of years, so that restocking does not need to be done annually. The Imperial Irrigation District established its own grass carp hatchery in 1988, producing 10,000 to 20,000 stockable fish per year (Imperial Irrigation District Public Information Office 1998c). It is illegal in California to catch or possess grass carp.

It is not yet known whether grass carp will also eat the noxious floating fern *Salvinia molesta* (Table V) which was introduced in 1999 into the Colorado River and All-American Canal (*Los Angeles Times* 23 September 1999). *S. molesta* is, after the water hyacinth *Eichhornia crassipes,* the most widespread aquatic weed in the world (Oliver 1993; Room and Fernando 1992). An aquatic beetle, the weevil *Cyrtobagous salviniae* has been used effectively in biological control of salvinia elsewhere in the world (Cilliers 1991) and should be considered for the Salton Trough if can be demonstrated that it will not feed on other, desirable plants. Both hydrilla and salvinia are readily spread by boaters.

Mearns (1975) predicted that introduced tropical fish would not likely threaten Salton Sea sport fish, but that tropicals very likely would become major competitors of the native *Cyprinodon macularius.* This pessimistic prediction has become reality, as documented by Schoenherr (1979, 1981, 1988). Swift et al. (1993) and Dill and Cordone (1997) provided detailed reviews on introduced fish species in southern California. Swift et al. (1993) regarded as "introductions" native California fish introduced outside their native range; Dill and Cordone (1997) ignored intra-state introductions.

5. Birds

"Birds are often completely ignored in limnological studies in spite of the fact that they may play very important roles in a lake's ecology" (Hammer 1986). The marshes and riparian vegetation of the Salton Sea edges, rivers, lakes, springs, seeps, canals, and drains provide an oasis of habitat for water-related birds amid the broad cultivated fields of the Imperial and Coachella Valleys and the surrounding Colorado Desert. Bird populations at or immediately around the Salton Sea on almost any given day number at least in the low hundreds of thousands, and at times reach the low millions (Shuford et al. 1999).

There are two wildlife refuges along the Sea's shoreline: the federal Sonny Bono Salton Sea National Wildlife Refuge at the south end of the Sea (US Fish and Wildlife Service 1999c), and the state Imperial Wildlife Management Area (Wister Unit, 1580 ha, along the southeast margin of the Sea; Finney-Ramer Unit, 1820 ha, along the Alamo River; Hazard Unit, adjacent to and managed by the federal refuge) (Gillilan 1971; Nathanson 1972). The federal refuge, established in 1930, originally consisted of 5,789 ha bordering a considerably smaller Salton Sea. The refuge later leased an additional 5,931 ha from the Imperial Irrigation District for its present refuge. Because of flooding, only ~432 ha of manageable habitat remain. The state's Imperial Wildlife Refuge was formed in 1954. Both refuges provide shallow waters and abundant food to attract wintering waterfowl away from agricultural fields to reduce crop depredation. Both refuges allow fishing and seasonal bird hunting (chiefly ducks, geese, doves). Wister's hunting use has varied from ~11,000 hunter-days per year to ~5000 hunter-days per year. The level in 2000 is ~8000 hunter-days year (Salton Sea Authority and US Bu-

reau of Reclamation 2000a). Both refuges have become major sites of recreation, with bird watching now the major use. Refuge personnel buy high-quality irrigation water to dilute used agricultural water in the refuges, a short-term solution to high salinity that is very expensive.

More than 400 bird species have been recorded at the Salton Sea (US Fish and Wildlife Service 1997a; Shuford et al. 1999), including a number of rarities observed nowhere else in the western US. This number is over half the total number of bird species recorded for all of North America north of the Mexican border, and is rivaled only by the number of birds recorded for the Texas coast of the Gulf of Mexico. The Salton Sea area is the major center of avian diversity in the American west. Checklists of birds are available from the federal refuge and the Salton Sea State Recreation Area visitor center, though they can never be complete nor up to date (US Fish and Wildlife Service 1997a; Shuford et al. 1999).

Salton Trough bird life falls into several important categories:

- Resident species of desert plant communities, most abundant near water and agricultural lands, as well as residents of the Salton Sea shoreline and adjacent marshes. Additional species are resident in agricultural fields and towns.
- Winter visitants, notably grebes, ducks, geese, shorebirds, and other migratory birds attracted to water and cultivated fields which provide food and shelter.
- Spring and fall migrants along the Pacific Flyway.
- Summer visitants, many of which breed, sometimes in large numbers.

With an increasing number of birders present during the intense heat of the summer, it is becoming apparent that many bird species regularly disperse northwards to the Salton Sea in late summer after breeding in México, some in large numbers, others exceedingly rare. These include blue-footed booby (*Sula nebouxii*), magnificent frigatebird (*Fregata magnificens*), roseate spoonbill (*Ajaia ajaia*), wood stork (*Mycteria americana*), Heermann's gull (*Larus heermannii*), laughing gull (*Larus atricilla,* which bred for a few years from the 1920s through 1957), and yellow-legged gull (*Larus livens*). Amazingly, there are several recent records of the Laysan albatross (*Phoebastia immutabilis*), normally an open Pacific Ocean bird. Some of these late summer visitors have recently established breeding populations, including brown pelican (*Pelecanus occidentalis*) and black skimmer (*Rhynchops niger* (Table X). Late summer *chubascos* may even force open ocean birds such as boobies (*Sula* spp.), storm-petrels (*Oceanodroma* spp., *Oceanites* spp.), and jaegers (*Stercorarius* spp.) onto the Sea (Kaufman 1977; Patten and Minnich 1997). We may expect additional reports of accidental rarities as the number of summer birders continues to rise.

Colonial nesting species at the Salton Sea include brown pelican (*Pelecanus occidentalis,* since 1996), white pelican (*Pelecanus erythrorhyncos,* not since 1957), double-crested cormorant (*Phalacrocorax auritus,* since ~1907), great blue heron (*Ardea herodias,* since ~1907), great egret (*Ardea alba,* since ~1961), snowy egret (*Egretta thula,* since ~1978), little blue heron (*Egretta caerulea,* once in 1979, near Seeley), tricolored heron (*Egretta tricolor,* once in 1994, at Ramer Lake), cattle egret (*Bulbulcus ibis,* since 1970), black-crowned night heron (*Nycticorax nycticorax,* since 1986), white-faced ibis (*Plegadis chihi,* sporadic

breeding since 1950s), western snowy plover (*Charadrius alexandrinus*), laughing gull (*Larus atricilla,* since 1920s, but not in recent years), California gull (*Larus californicus,* since 1997), gull-billed tern (*Sterna nilotica* since 1927), elegant tern (*Sterna elegans*), Caspian tern (*Sterna caspia,* since 1920s–1930s, ceased in 1950s, with recolonization in 1992), Forster's tern (*Sterna forsteri,* since 1970), and black skimmer (*Rhynchops niger,* since 1973). Note that many of these species colonized the Sea relatively recently. Ground-nesting colonial waterbirds must contend with one of the world's hottest and most rigorous places to nest and raise chicks. See Shuford et al. (1999) for details on colonial nesting birds at the Salton Sea.

The cattle egret is a natural introduction to the Western Hemisphere from Africa in the 1930s. It was first recorded from the Salton Trough in 1963, and first nested in the Imperial Valley, at the New River delta, in 1970. Cattle egrets soon displaced snowy egrets from many tree and snag nesting sites, and are now the most common ardeid in the Salton Trough (Platter 1976; Small 1994; Shuford et al. 1999).

Pelicans, cormorants (which also nest in trees), snowy plovers, gulls, terns, and black skimmers all nest on the ground, either on islets or barnacle shell "sand" bars (Small 1994). These environments are vulnerable both to land-based predators such as raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), coyotes (*Canis latrans*), kit foxes (*Vulpes macrotis arsipus*), domestic dogs (*Canis familiaris*), and feral house cats (*Felis catus*), etc., and to inundation by seasonally rising Salton Sea waters. In 1995, federal refuge personnel created five artificial islets in three shallow waterfowl management ponds, normally drained during the summer, managing water levels to maintain islet status. The immediate and happy result is that a large majority of the Salton Sea's gull-billed terns (in 2000 ~180 pairs) and black skimmers nest on these islets; in 1997 Caspian terns began nesting. Refuge personnel (pers. comm.) reported that this project has continued to be successful and is expected to expand with the creation of more managed nesting islets.

Birding on both federal and state wildlife refuges in Imperial County is big business; birders from around the world spent $3.1 million during the year September 1993 through August 1994 (Ornithological Council 1998). That year avian enthusiasts came from 7 countries, 31 states, and 20 California counties.

Benthic-feeding and Planktivorous birds.—American avocets (*Recurvirostra americana*) and black-necked stilts (*Himantopus mexicanus*), both of which breed in the Salton Trough in large numbers, and many other smaller, mostly migratory, shorebirds (Charadriiformes) probe-feed on small invertebrates (worms, crustaceans, insects) along the Salton Sea shoreline, in shoreline pools, drowned fields, and in other waters shallow enough to wade in. American avocets sweep and filter the water above the substrate with their upwards-curved bills. The rare summer visitant roseate spoonbill is a zooplankton feeder. Some 44 species of shorebirds have been found at the Salton Sea, four or five of which breed. Vast numbers appear during migration. The Salton Sea is one of the most important sites along the Pacific Flyway for wintering and migrant species. Shorebird populations averaged as many as 90,000 individuals in April between 1978 and 1987 (Shuford et al. 1999). The great abundance of wintering and migratory shorebirds in the

Colorado delta has led to its recognition by the Western Hemisphere Shorebird Reserve Network (Mellink and Ferreira-Bartrina 2000). It is unlikely that any of these avian planktivores and benthic feeders, however abundant, have any significant ecological effect on the overall ecology of the Salton Sea itself, except perhaps in certain marginal areas (Oglesby pers. obs.).

From many hundreds of thousands to three to four million eared grebes winter (November through April) on the Salton Sea, as much as 90% of the world's population of this species. Eared grebes at the Sea feed primarily on pileworms, small insects, and crustaceans (Jehl 1996, 1997, 2000; Warnock 1999; Kuperman et al. 2000). See below for discussion of major grebe mortality events.

Thirty-six species of swans, geese, and ducks have been recorded from the Salton Sea area, most occurring as migrants and winter visitors; only five species have been confirmed as breeders. The Salton Trough is second only to the Central Valley for wintering waterfowl. Commonest are snow (*Chen caerulescens*) and Ross geese (*Chen rossii*), ruddy ducks (*Oxyura jamaicensis*), northern pintail (*Anas acuta*), northern shovelers (*Anas clypeata*), American wigeon (*Anas americana*), green-wing teal (*Anas crecca*), Canada goose (*Branta canadensis*), scaup (*Aythya marila* and *A. affinis*), and canvasback (*Aythya valisneria*) (Shuford et al. 1999).

Piscivorous birds.—At all times of the year, piscivorous birds are abundant, both along the Salton Sea shoreline and on the open Sea itself.

Beginning many years ago a few brown pelicans (federally listed as Endangered in 1970) summered at the Salton Sea after nesting in the Gulf of California, with numbers increasing in recent years. Brown pelicans first overwintered in 1987, and began breeding on Mullet Island in 1996. This colony is the only breeding site away from the Pacific Ocean coastline (including the Gulf of California), but constitutes only a tiny fraction of the total brown pelican population in the eastern Pacific Ocean. Since the mid-1990s, summer post-breeding populations of brown pelicans regularly reach 1000 to 2000 birds, with 10 to 20 birds overwintering (Imperial Irrigation District 1994; Anderson et al. 2000).

White pelicans, which breed at inland saline lakes throughout the west, have always been present in the Salton Trough as they migrated to winter in the Colorado Delta; they still use the Delta when there is water present. White pelicans began breeding at the Salton Sea as soon as it formed in 1905 to 1907, using small islets near the five volcanic buttes—this was the southernmost known nesting colony (Grinnell 1908). The last confirmed breeding was in 1957, after which the last few breeding islets were inundated by the rising Salton Sea. Several thousand (2000 to 17,000) white pelicans winter at the Salton Sea, most of the western US population (Friend 1999), but numbers seem to have declined in recent years, as they have over all of western North America due to habitat loss and human disturbance. Both pelican species feed primarily on tilapia, with white pelicans able to take larger fish (up to 2 kg) than brown pelicans (up to 1 kg) (Imperial Irrigation District 1994).

Double-crested cormorants have declined regionally because of pesticides; predation of eggs and young by crows, ravens, and gulls; habitat losses; and human disturbance. Cormorants have bred on islets and snag trees at the Salton Sea since at least 1980 and probably since the formation of the Salton Sea in 1905. In fact

an old name for Mullet Island was Cormorant Island. About 10,000 cormorants are now resident, with their major nesting location on Mullet Island (as many as 4500 nests—the largest breeding colony on the West Coast); other Salton Sea breeding colonies include the Whitewater River delta and near the Wister Unit of the state game refuge. Cormorants feed and roost both at the Salton Sea and at Finney and Ramer Lakes. They also feed at the New and Alamo Rivers (Imperial Irrigation District 1994).

Ospreys are open-water piscivores, but are uncommon at the Salton Sea. Bald eagles are also piscivores, usually robbing other birds (kleptoparasitism); as many as 1 to 3 winter at the Salton Sea (Imperial Irrigation District 1994).

Shoreline-associated piscivores additionally include a number of species of herons and egrets, white-faced ibis, several species of rails, and wood storks. Despite statements to the contrary (e.g. US Bureau of Reclamation 1998a) cattle egrets are not piscivores; they are terrestrial birds, eating insects, spiders, other terrestrial invertebrates, lizards, and mice, but only a few fish (Platter 1976). Black skimmers feed on surface fish on the wing, but do so only in very nearshore waters, not the open sea. Black skimmer populations, nesting colonies, and reproductive success vary greatly in size from year to year (Molina 1996). Up to 40% of the California population nests at the Salton Sea (Friend 1999).

Feeding of these piscivores has been little studied at the Salton Sea. For example: What fish species and sizes do they feed on? What is the effect of predation on the population biology of their prey? Piscivorous birds may have a significant impact as top predators in Salton Sea food webs (Oglesby pers. obs.).

For four years beginning in 1987, the US Fish and Wildlife Service made annual counts of active nests of great blue herons, great egrets, snowy egrets, cattle egrets, and double-crested cormorants in the Imperial Valley. This breeding census presented a dismaying picture: a steady decline through the four year study period, and apparently no young produced at all in 1990. Fish populations in drains and in the Salton Sea had not comparably declined, suggesting that food was not limiting the four piscivores. A major problem in assessing potential adverse effects from pollutants is the fact that these species feed not only on the Sea and but also in lakes, canals, irrigation drains, riparian habitats, and irrigated fields. Cattle egrets eat almost no fish, and their nesting crashed similarly to those of the piscivores. The US Fish and Wildlife Service believed that trace metal buildup might have been responsible, presumably derived from runoff into the closed Salton Sea, though in fact trace metal concentrations are not elevated in the Sea (see below). Nevertheless, all five species were still abundant at the Salton Sea in 2000 (Oglesby pers. obs.). High winds can cause significant nest failure in heron and egret nesting colonies in trees in the federal wildlife refuge (Barnum 2000).

Recent proposals for "saving" the Salton Sea have focused on only five species on the Federal List of Endangered Species: brown pelican, bald eagle, peregrine falcon (delisted in 1999), Yuma clapper rail, and California least tern (Table X). The Salton Sea population is critical for only one of these species, the Yuma clapper rail (~300 breeding pairs, about 40% of the state's population: Friend 1999). Brown pelicans have recently started to breed at the Sea but coastal colonies will always be much more productive. The California least tern, osprey, and bald eagle are rare visitants. It is a serious mistake for planners to focus so

narrowly on these five species. Table X lists 68 rare species which are on either or both Federal and California Lists of Endangered, Threatened, and Special Concern Species, because of declining ranges, declining populations, nest parasitism, competition, or combinations thereof. About 20 of these rare species are intimately tied to the Salton Sea and riparian habitats. All five alternatives for "restoration" of the Salton Sea presented by the Salton Sea Authority and US Bureau of Reclamation (2000a) (see below) have acknowledged the potential for significant adverse impacts, mostly localized, on Salton Sea-related birds. If planning for "restoration" of the Salton Sea involved planning to maintain and improve populations of all 68 of these rare species, all 400+ Salton Trough avian species would greatly benefit.

6. *Food Chains and Webs*

The main food chains in the Salton Sea leading to the four sport fish are short and unusual in composition. There is no significant zooplanktivore, though very young bairdella (Quast 1961), and corvina as well, feed on zooplankton for a short time. Most phyto- and zooplankton, feces, and dead fish sink to the bottom and become rich organic detritus. The only major detritus feeder is the vastly abundant pileworm, *Nereis succinea.* The quasi-marine food chains leading to Salton Sea sport fish are fragile and could be easily upset, particularly by introductions of new fish species, such as a major zooplanktivore or another top carnivore. Because of the low diversity of the Salton Sea, each successive link is vital to the survival of species in higher trophic levels; there are no alternate trophic pathways.

In the 1950s, a research group headed by B. W. Walker from the University of California at Los Angeles studied the ecology of the Salton Sea for four years in conjunction with Department of Fish and Game fish introductions. Their report (Walker 1961), though now representing work >45 yr old, is the most recent and comprehensive, and perforce still the best, survey of the biology of the Salton Sea. The ecological roles of more recent introductions, such as tilapia, the amphipod *Gammarus mucronatus,* and the polychaete *Streblospio benedicti* have not yet been well studied. Walker et al. (1961b), Young (1970), Isaacs (1972, 1973), Hogg (1973), Kim (1973), Lange and Hurley (1975), and Mearns (1979) discussed overall trophic relations in the Salton Sea. None of these papers could address the ecosystem of the 1990s. A group headed by Stuart Hurlbert at San Diego State University began a comprehensive study of Salton Sea ecology in the late 1990s (D. Dexter pers. comm.; S. Hurlbert, pers. comm.). Their results will greatly advance our knowledge in this area.

The major food chains in the Salton Sea are:

1. Phytoplankton → herbivorous zooplankton → death of plankton + feces → bacterial decay forming organic detritus on the bottom plus bacteria and other benthic micro-organisms → detritivores (especially pileworms and amphipods) → benthic-feeding organisms (fish, birds, especially eared grebes) → fish and birds that feed on benthic feeding organisms (modified from Walker et al., 1961b). This detritus-based food chain is at least unusual in large lakes, and may be unique, though detritus-based food chains are common in estuaries, where planktonic food chains are usually also important.

The Salton Sea lacks planktivorous fish, except for the mostly irrelevant threadfin shad.
2. The tilapia food chain seems to be: phytoplankton → herbivorous zooplankton → death of plankton + feces → bacterial decay forming organic detritus on the bottom → benthic algae, pileworms, insects, crustaceans, small fish → tilapia → orangemouth corvina, brown and white pelicans, other piscivorous birds.
3. The orangemouth corvina food chain in the Salton Sea is: phytoplankton → herbivorous zooplankton → death of plankton + feces → bacterial decay forming organic detritus on the bottom plus bacteria and other benthic micro-organisms → detritivores (pileworms, amphipods) → benthic-feeding fishes (bairdiella, sargo, tilapia?) → young orangemouth corvina) → piscivores (larger orangemouth corvina, birds).
4. A minor, seasonal variation involving the one pelagic planktivore, threadfin shad: phytoplankton → herbivorous zooplankton (adults, larvae) → threadfin shad → orangemouth corvina, many birds.

Walker et al. (1961b) strongly warned against further introductions of top-of-the-food-chain carnivorous fishes unless the newly developing fishery in the 1950s did not succeed, and advised great caution in introductions of any other animals or plants to the Salton Sea. Their one exception was based on their concern that the pileworm *Nereis succinea* is the major trophic link between plankton/detritus and the sport fishes. They suggested introducing several species of mysid and amphipod crustaceans and perhaps other polychaetes to become alternate food sources for the fish. Fortunately, tilapia, introduced in the 1970s, seem to have augmented the sport fishery of the Sea rather than disrupting it. Curiously, Costa-Pierce and Riedel (2000) and Riedel and Costa-Pierce (2000) suggested stocking new species of predatory game fish, without discussing the likely adverse effect—perhaps severe—on the popular fishery for orangemouth corvina and the other sport fishes. It is important to keep in mind the warnings of Walker et al. (1961b).

Major Fish and Bird Mortality Events: Toxins, Pathogens, and Parasites

Fish kills and bird die-offs have been known in the Salton Sea since its formation in 1905 to 1907 (Cohen et al. 1999; Friend 2000c), and have continued regularly ever since. We have seen sometimes massive kills of bairdiella, tilapia, eared grebes, puddle ducks, ruddy ducks (*Oxyura jamaicensis*), geese, and coots (*Fulica americana*) both in summer and winter since 1968 (Oglesby pers. obs.). Many recent writers believe that fish and bird die-offs have become more frequent and more severe in the 1990s, and that they are indicative of an increasingly stressed Salton Sea ecosystem (e.g., Cohen et al. 1999; Cohn 2000; Friend 1999, 2000c). But it is not at all clear whether the recent, well-publicized mortality events represent real increased mortality, or that a now-sensitized press is publicizing "ordinary" mortality more than before, when even large die-offs were neglected except by refuge and state park personnel, fishers, residents, and regular visitors (Costa-Pierce 1998a; Oglesby pers. obs.).

Many, if not most, fish kills at the Salton Sea over the past century have been caused by: (1) hypoxia created by wind-driven mixis, especially during the summer, bringing oxygen-deficient and sometimes S^{2-}-rich and NH_4^{1+}-rich hypolimnic

water to the entire water column. Hypoxic fish kills have also been attributed directly to intense algal blooms (Salton Sea Authority and US Bureau of Reclamation 2000a; many other reviewers and popular writers), although the evidence for this is not persuasive. (2) Food deprivation in bairdiella during the summer when pileworms vanish from deeper waters. This mortality may propagate up the food chain. (3) Low temperatures adversely affecting tilapia in winter (see above). Often, bird and fish mortality events at the Salton Sea simultaneously occur at other lakes and marshes in the western US (Costa-Pierce 1998a), suggesting that region-wide issues are involved, rather than just at the Salton Sea.

A headline in the *Los Angeles Times* for 12 August 1999 was "7.6 million fish die in a day at Salton Sea." The fish were tilapia. The *Times* went on to say, "Residents contend that despite the numbers [the deaths are] just as much a part of the Salton Sea as summer heat. Some scientists, however, say the die-off is yet another omen of the sea's demise, and they warn that the end may be approaching faster than expected." Costa-Pierce was quoted: "The Salton Sea is dying. Our response plan needs to be rapid, or I give it a couple of years before we have massive die-offs year round. This is just the beginning." Such a sudden, one-time die-off is unlikely to have been the result of chronic or gradually changing factors such as salinity, temperature, algal blooms, or contaminants from agricultural or industrial wastes. Most likely, the August 1999 die-off was the result of a rapid wind-caused turnover of the Sea, bringing hypoxic hypolimnic water to the surface and reducing the O_2 concentration in the entire water column to below the hypoxia threshold of tilapia. A longtime resident was quoted: "They keep saying this is unprecedented. But we've been here over 20 years and every time that water churns up in the summer, we have dead fish. You have to live here to understand."

Jim Matthews, Outdoors columnist for the Ontario CA *Inland Valley Daily Bulletin*) pointed out on 12 August 1999 (the same day): "The die-off mostly affected tilapia on the northeast end of the sea and was a drop in the bucket compared to what the sea holds. At the same time the die-off was taking place, the corvina action on the other side and south end was the best it has been in over a decade. This is the best fishing anywhere right now." The figure of 7.6 million dead tilapia must also be questioned. While available accounts gave no information as to how total deaths were estimated, probably the figure was based on counts on short stretches of beach, scaled upwards to cover the entire shoreline. This procedure would vastly overestimate the total since other shorelines had few dead fish.

Large-scale mortality events involving eared grebes have been documented in the West, including both Mono and Great Salt Lakes, for more than a century, attributed to disease, inadequate pre-migration fattening, and adverse weather during migration (Jehl 1996). Jehl observed that a three-year meromixis period in Mono Lake beginning in 1996 led to reduced weight gain during fall migration and apparently more stress on the grebes when they wintered at the Salton Sea; they did fine in 1999 (Little 2000).

Toxins.—In winter 1991–1992, a large number of eared grebes and some other wintering waterbirds washed up dead along the Salton Sea shoreline. The number was estimated at $>$150,000 dead grebes, $\sim$10% of the grebes wintering that year

on the Sea (Jehl 1996; Warnock 1999; Franson et al. 2000; US Geological Survey National Wildlife Health Center 2000). Living and dead birds were concentrated at the mouths of large drains and the three rivers, and scavengers were very active, according to federal refuge personnel (deBuys 1999). The cause of the 1991 to 1992 grebe deaths was controversial right from the start, with toxic algae (the pelagic bluegreen alga *Microcystis*), mercury (Hg), and selenium (Se) all being held responsible. A decade later, there is still no evidence for microcystin (or anything else) being specifically responsible.

Reifel et al. (2000a) used an *Artemia* bioassay to see if a number of potentially toxic Salton Sea phytoplankters (listed in Table IV) would be toxic to fish or birds. Some of these algae were toxic in the *Artemia* assay, but had no effect on mice. The most studied of these was the raphidiophyte *Chattonella marina,* which produces both brevetoxins and superoxide radicals and can cause massive die-offs in aquaculture facilities as well as in the nearshore ocean, notably around Japan and Australia (Coe et al. 2000; Tiffany et al. 2000a). At the Salton Sea, *C. marina* blooms up to 600 cells per milliliter from April through November, when the water is in excess of ~24°C (Horvitz 2000) with characteristic damage to fish gills. Tiffany et al. (2000a) thought that the absence of this alga in the plankton during winter means that it overwinters as cysts in the sediment.

Investigators continue to explore the potential for algal toxins to cause major problems in Salton Sea biota.

Pathogens.—Waterbird die-offs have occurred regularly for many decades at the Sea, and those caused by several pathogens have been well studied at the Salton Sea or elsewhere (Shuford et al. 1999).

Newcastle virus killed ~1600 cormorants and 100 Caspian terns in 1997 and 1998; these were the largest kills in the entire US attributed to Newcastle disease (Kaiser 1999; Daszak et al. 2000; Friend 2000c; US Geological Survey National Wildlife Health Center 2000). Despite many reports to the contrary, Shuford et al. (1999) concluded that it was not possible to determine the age of affected cormorants and terns—they may well not have been nestlings but one or two years old. Newcastle virus type C was unknown in double-crested cormorants west of the Rocky Mountains until 1977 (Shuford et al. 1999). The Salton Sea cormorant strain of Newcastle virus is the mesogenic strain, different from the one that causes serious disease in parrots and galliform birds such as chickens (velogenic strain), first identified in the US in 1944. Newcastle virus is a paramyxovirus, a group of often virulent viruses that cause such diseases as rinderpest in cattle, canine distemper, and human measles. Newcastle virus is readily transmitted by ingestion, inhalation of aerosols, and contact with infected hosts and contaminated materials. It can remain infective for weeks in nature over a wide range of *p*H and temperature, and in litter, soil, and carcasses for at least 255 days. Humans may get a mild, self-limiting infection (U.S. Geological Survey National Wildlife Health Center 2000). Immediate removal of bird carcasses is important in control of outbreaks; workers must exercise strict sanitation to prevent transmission to other birds.

Avian (fowl, chicken) cholera has caused sometimes large bird kills at the Salton Sea for many years, chiefly in ducks and geese, especially snow and Ross geese. Around 60,000 to 100,000 snow geese winter at the Salton Sea, along with

a small number of Ross geese. This disease is primarily present in winter. Avian cholera is a long-known avian disease caused by the bacterium *Pasturella multocida* Type 1, unrelated to the bacterium that causes human cholera and related diseases (*Vibrio* spp.). In 1880 to 1882 Louis Pasteur used chicken *P. multocida* in establishing both the germ theory of disease and the value of vaccination. Though well known as a poultry disease, avian cholera in wild waterbirds was first reported in North America in 1944 near San Francisco and Texas, and at the Salton Sea in 1979; it is now widespread in the US.

Pasturella multocida is highly contagious and easily transmitted by direct contact between birds as well as by contaminated soil, food, and water. It is also virulent, killing birds in as few as 6 to 12 hours after infection, and often causing mortalities of >50%. Sick birds are lethargic, poorly coordinated, and erratic in flight (dying birds may just fall from the sky). *P. multocida* does not over-summer in the absence of vulnerable birds; rather, the Salton Sea and all other wintering sites are reinfected every year by now-immune migratory birds who survived avian cholera in their northerly breeding grounds (US Geological Survey National Wildlife Health Center 2000). *P. multocida* was found in 21% of Salton Sea eared grebe carcasses necropsied since 1991 (Franson et al. 2000; US Geological Survey National Wildlife Health Center 2000). Here again, immediate removal of carcasses is important in control of outbreaks; workers must exercise strict sanitation to prevent transmission to other birds.

A large late-summer 1996 bird kill—>8500 white pelicans (~15% of the entire population of this species in the west), ~2000 brown pelicans (~20% of the state's population), and >4500 birds of ~60 other species—was eventually attributed to avian botulism. Avian botulism is caused by the anaerobic bacterium *Clostridium botulinum* Type C and, to a much lesser extent, Type E (not the human botulism strains A, B, and F). Type C is cosmopolitan, found in ducks and geese, shorebirds, colonial waterbirds, and a few others; scavenging birds such as turkey vultures (*Cathartes aurea*) are resistant. Type E is found in gulls and loons and has been reported so far only from the Great Lakes region. At the Salton Sea, avian botulism is well known in puddle ducks and coots, both of which eat decaying vegetation. *Clostridium botulinum* is a strict anaerobe which forms dormant spores which can survive for years under anaerobic conditions in soil and organic matter in wetlands, including carcasses. Spores are highly resistant to environmental stresses such as extreme temperature and desiccation (US Geological Survey National Wildlife Health Center 2000).

Transmission of avian botulism at the Salton Sea is attributed to ingestion of spores found in a wide range of living and dead vertebrates, such as tilapia, and invertebrates, especially, maggots of flesh flies (Sarcophagidae) and blowflies (Calliphoridae). In 1996 sick brown pelicans were found with *C. botulinum*-infected tilapia in their guts (Costa-Pierce and Riedel 2000). Up to 50,000 maggots can occur in one bird carcass; ingesting as few as 3 to 5 infected maggots can kill a duck. Bacteriophage-infected *C. botulinum* produce a paralytic neurotoxin, botulinum, which is transmitted directly to birds in their food. The resultant muscle paralysis leads to inability to hold the neck up ("limberneck") and then to death by drowning, respiratory failure, altered salt and water balance, or predation. Control of avian botulism necessitates quick removal of fish and bird carcasses. Early treatment can save diseased birds, but since this is expensive, it is usually

reserved only for endangered species (US Geological Survey National Wildlife Health Center 2000).

Anywhere from a few hundred to tens of thousands of ducks die from avian botulism each year at the Salton Sea. Nationwide, from a few hundred thousand to over a million birds may die each year; the disease seems to be increasing everywhere, not just at the Salton Sea (Shuford et al. 1999). Avian botulism has long been present in late spring and summer at the Sonny Bono Salton Sea National Wildlife Refuge, though never before to the extent seen in July to September 1996, and not before then to any significant extent in fish-eating birds. In 1996 there were massive acute infections in Salton Sea tilapia with *Vibrio (Photobacterium) alginolyticus,* a bacterium well known for causing fish kills in waters with extreme conditions such as high temperature, high salinity, pollution, or overcrowding. Humans can develop rashes after eating *V. alginolyticus*-infected fish. *V. alginolyticus* has been found at the same Salton Sea sites as *C. botulinum* Type C, and, in one case, a mixed infection of both species in one fish. Other species of bacteria were cultured from partially decomposed tilapia, including *V. damsela, Pseudomonas* (*Shewanella*) *putrefaciens* and a *Bacillus* sp. (US Geological Survey National Wildlife Health Center 2000).

The relationship between acute *Vibrio alginolyticus* infection in tilapia and avian botulism is not established, but biologists from the US Geological Survey National Wildlife Health Center (2000) suspect that *V. alginolyticus* may produce anaerobic conditions in fish guts that allow *Clostridium botulinum* spores to germinate and produce botulinum. Avian botulism is probably spread directly to fish-eating birds which ingest maggots while feeding on *C. botulinum*-infected fish carcasses, or rotting tilapia with *C. botulinum* in their guts, though wild pelicans rarely eat dead fish (*New York Times* 24 March 1998; deBuys 1999; US Geological Survey National Wildlife Health Center 2000; a number of articles in the *Los Angeles Times*). A few brown pelicans infected with avian botulism were found after the large August 1999 die-off of tilapia. Another die-off of brown and white pelicans occurred in summer 2000, though apparently there was no significant fish mortality and no other birds were affected; several hundred pelicans were released in November on the seacoast after rehabilitation (*Los Angeles Times* 10 July 2000, 30 August 2000; KNBC-TV local news November 2000). No other outbreak of avian botulism has equaled the one in 1996.

Though many writers (e.g. Rocke and Nol 2000) state that avian botulism is only newly recorded from the Salton Sea, we have seen sometimes large numbers of herbivorous ducks and coots that died from avian botulism on and near the federal wildlife refuges since at least the late 1960s (federal refuge personnel, pers. comm.), and Shuford et al. (1999) stated that the disease has been present since at least 1939. What seems to be new is that piscivorous birds are now involved (Rocke and Nol 2000; US Geological Survey National Wildlife Health Center 2000). Franson et al. (2000) found only 2% of eared grebe carcasses necropsied since 1991 to be positive for avian botulism, but most grebes migrate north before the avian botulism season of late spring and summer.

A few avian deaths from *Salmonella* infections have recently been reported (Shuford et al. 1999; Friend 2000c), but may have been overlooked prior to the late 1990s. Avian salmonellosis is commonly recorded in passerine birds at bird feeders, spread both from food to bird and from bird to bird (US Geological

Survey National Wildlife Health Center 2000). A kill of 4,500 cattle egrets and some other ardeids in the Imperial Valley in 1989 was attributed to salmonellosis (Shuford et al. 1999; Salton Sea Authority and US Bureau of Reclamation 2000a).

The dinoflagellate *Amyloödinium ocellatum* is a major fish pathogen in aquaculture facilities, home marine aquaria, and in tropical and sub-tropical ocean nearshore environments. Fish deaths can occur within 12 hours of initial infection in laboratory cultures, though most infected fish live several days. Long-lived (4 to 6 weeks at least) flagellated dinospores are the dispersal, reproductive, and infective stage; the trophic stage is ectoparasitic. The species also develops cysts. The life cycle can be completed in ~1 week. Infected fish exude mucus from their gills, breathe rapidly, and gasp for air due to extensive gill epithelial damage (US Geological Survey National Wildlife Health Center 2000). At the Salton Sea, tilapia seem to be the major fish infected with *A. ocellatum* (Friend 2000c). Infection rates were high on Salton Sea fish during spring and summer 1997 to 1999, with up to 100% of examined fish infected with *A. ocellatum.* Gills and skin are often severely damaged, which can readily lead to respiratory failure as well as secondary infections by other pathogens such as bacteria, viruses, and fungi (Kuperman and Matey 1999, 2000). In September 1997, a large tilapia kill (>1 million fish) was attributed to *A. ocellatum* (US Geological Survey National Wildlife Health Center 2000). It is not yet known whether this pathogen has any significant effect on tilapia population biology, and its potential for damage to the Salton Sea ecosystem is unknown.

Parasites.—Several monogenetic and digenetic flukes have been reported in Salton Sea fish. Barlow (1963) wrote, "The Salton Sea [longjaw mudsuckers] at times are heavily infested with a monogenetic trematode [on the gills], but so are coastal populations." It would be easy to introduce additional coastal parasites to Salton Sea fish with longjaw mudsucker bait imported from Baja California, if appropriate intermediate hosts are also present in the Sea. Introductions of fish from any source could introduce parasites such as nematodes, tapeworms, flukes, and diverse crustaceans. Fish to be introduced should be screened for parasites.

Because of recent reports of "unprecedented" fish and bird die-offs, there has been increased study of fish parasites that might be causative. Kuperman and Matey (2000), noting that environmentally-stressed fish are more susceptible to parasitic infections and can transmit infection to predators and scavengers such as birds and mammals, studied ectoparasites of both major Salton Sea fish and invertebrates. Ectoparasites were common on young tilapia, orangemouth corvina, bairdiella, and longjaw mudsuckers, as well as pileworms and copepods. The dinoflagellate gill parasite *Amyloödinium ocellatum* (see above), the peritrich ciliate skin parasite *Ambiphyra ameiuri,* the flagellate gill parasite *Cryptobia branchialis* (involved in an autumn 1997 outbreak at Bombay Beach), and two species of the skin and gill monogenetic trematode *Gyrodactylus, G. olsoni* and *G. imperialis,* were identified. The skin and parapodia of the pileworm *Nereis succinea* were parasitized by the peritrich ciliate *Epistylus* sp., and the copepod *Apocyclops dengizicus* was parasitized by another peritrich, *Rhabdostyla vernalis.* These parasites often infect fish in aquaculture facilities elsewhere where fish density is high. Gills and skin are often severely damaged, which can readily lead to respiratory failure as well as epithelial damage resulting in secondary infection (Ku-

perman and Matey 2000). The importance of these parasites to Salton Sea biota and ecology is not known.

Is the Salton Sea Polluted?

Much concern has been expressed in the popular media as well as more scientific publications (e.g., Schoenherr 1993a; Kaiser 1999, 2000) about contamination of Salton Sea biota, especially sport fish and birds, with pesticides, herbicides, and trace elements brought in by drainage from non-operative sewage systems in Mexicali, agriculture, cattle feed lots, municipalities, and Mexicali *maquiladoras.* Wambaugh (1992) in *Fugitive Nights* summarized this view: "Many of the migrant workers, particularly Asian boat people, liked to fish the salt water for local corvina, using illegal gill nets. The cops figured that anybody hungry enough to eat the mutant fish from that selenium-loaded water—polluted by agricultural waste—should be welcome to it." Reality is quite different. The popular story about heavy pollution in the Salton Sea is poorly supported by direct measurements. There should have been no surprise at the release of a report by the Salton Sea Authority (Salton Sea Authority and US Bureau of Reclamation 1999) that there were few to no pesticide residues or trace elements in Salton Sea biota. The high input of agricultural fertilizers leads to high primary and thus high secondary production, not pollution (González et al. 1998; Salton Sea Authority and US Bureau of Reclamation 2000a).

There are major problems in interpreting published data on potential pollutants: (1) Raw data are presented in sometimes immensely elaborate and unwieldy tables, with little or no synthesis or interpretation in accompanying text. (2) No lower detection limits are provided for most analyses (Is "<5" units at or below the limit of detection?). (3) Only rarely are any criteria or standards for concentrations potentially hazardous to wildlife or human public health presented (Should we be worried about a report of 135 units?). (4) Usually no statistical analyses are done, and, apparently often, only one sample per site or creature is analyzed. (5) No analysis of variability is presented. (6) No statistical comparisons are made (In regards to Nos. 4 and 5, is "15 units" in this animal from this site at this time significantly different from "9 units" from that animal at that site at that time?). (7) For the same reasons, it is often impossible to determine temporal or spatial trends. (8) Units vary. (9) Only sometimes is it stated whether the units are per wet weight or per dry weight. (10) There may be other, unstated, differences in analytical techniques that may lead to different results. Holdren (1999) assumed that if the testing agency were reputable and if standard analytical techniques were used, the results would be valid ("While no information was given on analytical methods used, the data were considered good because of the agencies participating in the study." "Data were produced with acceptable methods."). In fact, about all one can say is that some numbers are larger than others, but it is often not possible to determine whether such differences are biologically meaningful.

Pesticides.—In the 1970s, around 1800 metric tons per year of 120 different insecticides and herbicides were used on fields in the Imperial and Coachella valleys (US Department of the Interior and The Resources Agency of California 1974a,b; Layton and Ermak 1976). Concentrations of pesticides and their metab-

olites in drains and at the mouths of the New and Alamo Rivers were low, usually well below measured LD_{50} concentrations for fish (Swajian 1976). (The LD_{50} of a substance is the concentration which is a lethal dose for half those exposed to it.) Nevertheless, the California Department of Fish and Game documented six fish kills, totaling ~54,000 dead fish in the decade 1965 to 1975, in drains in the Imperial and Coachella Valleys from pesticides and other toxic agricultural wastes (Swajian 1976). The seemingly higher incidence of fish kills towards the end of the reporting period may reflect greater awareness of the problem (Swajian 1976). A spill of the insecticide thiodan in July 1996 killed 10,000 to 15,000 fish near the Hazard Unit of the Imperial Game Refuge (US Fish and Wildlife Service 1997d). Many insecticides are toxic to humans and fish, and should be monitored carefully in Salton Sea biota, including using appropriate statistical analyses.

Hogg (1973) analyzed Salton Sea biota and sediments for several pesticides commonly used in the Imperial Valley. He found the organochlorine insecticide DDT (1,1,1-trichloro-2,2-*bis* [*p*-chlorophenyl]-ethane) or its metabolites in 92% of all samples from the Salton Sea, and dieldrin in 42%. There was a non-significant south to north gradient in pesticide concentrations, and considerable seasonal variability, which Hogg attributed to fluctuations in pesticide application and to variability in runoff. While biological magnification in Salton Sea food chains was present, it was not marked. Hogg's conclusion was that the low pesticide concentrations he found posed no hazard to human health nor to the health of the Salton Sea biota.

A report in the early 1970s discussed what was then known about pesticide contamination of the Salton Sea and its biota, including fish. No data were given (US Department of the Interior and The Resources Agency of California 1974a,b). They said, "In all cases pesticide levels were found to be low, and it was concluded that there was no damage to fish from pesticide accumulation." The same report summarized a 1972 study which tested fish for pesticides: "The ranges of pesticide concentrations found were extremely low." DDT metabolites are very stable, persisting in the environment long after application. Even though DDT application was banned in 1972 in the US and in 1983 by México, concentrations of its more stable metabolite DDD (1,1-dichloro-2,2-*bis* [*p*-chlorophenyl]-ethane) in 1986 to 1987 as high as 50 to 60 milligrams per kilogram (mg kg^{-1}) were found in drain sediments, but Salton Sea sediments had only 2.4 mg kg^{-1} (Setmire et al. 1990; Setmire et al. 1993), in agreement with Hogg (1973). DDT is a contaminant in dicofol, an acaricide used on cotton (Cagle 1998), so there is still a certain level of DDT input into US agricultural drains and the Salton Sea. See Imperial Irrigation District (1994) and LFR (1999) for data on a number of pesticides; only chlordane, DDT and some of its stable metabolites, and toxaphene exceeded Food and Drug Administration or National Academy of Science guidelines, and then only in a few fish from only a few locations, none from the Salton Sea itself.

The Imperial Irrigation District (1994) summarized several studies on organochlorine concentrations in drain and Salton Sea waters, sediments, and biota. Except for stable DDT metabolites, concentrations were almost always below detection limits. Except for redfin shiners from the Whitewater River delta, total DDT (including its metabolites) was below federal guidelines; other fish tested were mosquitofish, sailfin mollies, and tilapia. Benthic invertebrates in drains had

higher concentrations than those from the Salton Sea, up to 8 to 20 times as high, with Asiatic river clams from Vail Drain having the highest; by striking contrast, Asiatic river clams from Wister Drain, which receives no agricultural drainwater, had no detectable organochlorines. Bioaccumulation tests with Asiatic river clams showed that DDE concentrations correlated with increased drain flows. The Alamo and New Rivers had higher organochlorine concentrations than did agricultural wastewaters in canals and drains by factors of 10 or more (California Regional Water Quality Control Board, Colorado River Basin 1991; Imperial Irrigation District 1994), perhaps reflecting high inputs from México. Recent studies showed four metabolites of DDT and three other pesticides were somewhat in excess of federal standards (Setmire 2000). Three volatile organics were also in excess of federal standards: tetrachloroethylene, methylene chloride, and n-nitrosophenylalanine.

Elevated concentrations of the DDT metabolite DDE were found in black-crowned night herons and great egrets nesting near the Salton Sea, correlated with slightly thinned egg shells. Both species could have fed either in the Salton Sea or in the many drains or both. The concentration of DDE in night heron eggs was slightly higher than that associated with reduced night heron reproductive success elsewhere in the US (Ohlendorf and Marois 1990). There have been no reports of reduced night heron nesting success at the Salton Sea, where they remain abundant (Oglesby pers. obs). Cattle egrets nesting in the Valle de Mexicali had somewhat elevated DDE concentrations, slightly thinned eggshells, and reduced hatching success, but they are insectivores and do not feed in the Salton Sea or drains (Mora 1991). Mora (1991) concluded that their reduced hatching success was caused by factors other than organochlorine pesticides.

The Salton Sea Authority and US Bureau of Reclamation (2000a) concluded that available data demonstrated a long-term decline in maximum concentrations of both pesticides and organics in the Salton Sea and its sediments, with the most recent studies finding such compounds below the concentration of detection.

Selenium.—The major potential pollutant of concern in the Salton Sea is the non-metallic element selenium (Se). A cofactor in the enzyme glutathione peroxidase, Se is required for human nutrition at a concentration of 0.04 milligrams per gram (mg g^{-1}); it is beneficial to humans up to 0.1 mg g^{-1}, and toxic above 4 mg g^{-1} (Cagle 1998).

It is unfortunate that the literature on purported Se problems in the Imperial Valley and Salton Sea rarely discuss the many serious problems experienced by nesting birds at Kesterson National Wildlife Refuge in the San Joaquin Valley. Agricultural wastewaters brought high concentrations of Se to shallow ponds and marshes at Kesterson, where many water-related birds spent the winter and bred during the summer. The problem was recognized beginning in 1983 because of a very high frequency of unhatched eggs and deformed chicks, most of which died soon after hatching. Kesterson was closed, and a number of remedial treatments were applied, based on extensive scientific research. The initially-favored soil removal plan was demonstrated to be ineffective in protecting ephemeral pools often favored by water birds. Groundwater was protected from Se contamination by natural biogeochemical immobilization. Upland vegetation did not much concentrate Se, and was regarded as safe. For these reasons, no attempt was made

to remove Se-contaminated soils; low-lying pools were filled to prevent birds from nesting, as aquatic food chains did lead to Se bioaccumulation. Important conclusions included: (1) Naturally-occurring biogeochemical processes can be the cornerstone of effective remedial strategies. (2) "Safe concentrations" of toxic constituents based on total elemental analyses may be misleading, and species-specific goals difficult to define. (3) Scientific research and fast-track remedial activities must go hand-in-hand to achieve cost-effective, risk-based remedial strategies (Harris 1991; Benson et al. 1993; Presser 1994). Bacterial pathways which convert Se to less-toxic organic species or which volatilize Se may be useful (Combs et al. 1996; Losi and Frankenberger 1997; Hanson 1998; Setmire and Schroeder 1998; Gao et al. 2000). The Salton Sea Authority and US Bureau of Reclamation (2000a), ignoring this extensive literature, made no recommendations concerning lowering Se concentrations in agricultural waters.

Various studies indicate that soils of the Salton Trough are not the source of its Se. Colorado River water has a concentration of ~2 micrograms Se per liter ($\mu g\ l^{-1}$), the Se being derived from erosion of sediments in the river's upper basin (Setmire and Schroeder 1998; Setmire 2000).

In the Imperial Valley, Se is concentrated by evaporation and leaching in agricultural fields (Craig 1966; Cagle 1998) so that Se concentration is much higher in agricultural drainwater than in incoming Colorado River water. Concentrations in the Whitewater River (which receives little agricultural waste) are lower than in the New and Alamo Rivers (Setmire et al. 1990; California Regional Water Quality Control Board, Colorado River Basin 1991; Colorado River Board of California 1992; Setmire and Schroeder 1998; Salton Sea Authority and US Bureau of Reclamation 2000a). Concentrations of Se in the Salton Sea are as much as 50% lower than in the rivers, apparently because Se is rapidly removed from the water column at the mouths of rivers and drains by benthic bacteria, sedimentation, and aerosolization (Setmire and Schroeder 1998; Setmire 2000; see below).

Drain sediments were always low in Se, within baseline ranges for soils in the western US. Concentrations in Salton Sea sediments were higher, as much as three times higher in a composite sample from the Sea (Salton Sea Authority and US Bureau of Reclamation 2000a). Curiously, highest Se concentrations in sediments were in the northern two-thirds of the Sea, with lower concentrations found in the southern third, which receives most of the direct agricultural drainage.

Se in Salton Sea biota is rarely concentrated enough to be of any concern either to public health or to bird reproduction, though Se concentrations in biota from rivers and drains can be markedly higher. The highest concentration of Se in plants, 1.1 milligrams per gram ($mg\ g^{-1}$), was found in sago pondweed (*Potamogeton pectinatus*), an important waterfowl food. At Kesterson concentrations of Se in bird food plants ranged as high as 310 $mg\ g^{-1}$ (Setmire et al. 1990; Schoenherr 1993a; Setmire and Schroeder 1998).

With a few unexplained exceptions, invertebrates in both drains and the Salton Sea had low concentrations of Se, all below the minimum 10 $mg\ g^{-1}$ dietary concentration that produced waterbird abnormalities in laboratory experiments (Imperial Irrigation District 1994).

Interpretation of Se analyses in water-related birds is greatly complicated by the fact that most waterbirds feed in several habitats: in the Salton Sea itself, the

major rivers and freshwater lakes (e.g., Finney and Ramer lakes and farm ponds), agricultural canals and drains, and agricultural fields, sometimes in the same day. The relative times spent feeding in each habitat are not known, and may vary with season. Therefore, it is not possible to conclude where a given bird or even species obtained its Se load.

Reported Se concentrations were higher than background in several species of Salton Trough birds, but well below concentrations found in deformed birds at Kesterson; most values from birds that feed away from the Salton Sea were well below the threshold for reduced reproduction and survival. Se concentrations in Salton Sea-feeding birds were somewhat higher, but not threatening. There was evidence of bioaccumulation at higher trophic levels, with Sea piscivores such as black-crowned night herons and pelicans at greatest risk (Imperial Irrigation District 1994; Setmire and Schroeder 1998; Shuford et al. 1999). Both brown and white pelicans from the Salton Sea had elevated Se concentrations compared with the same species from Sea World in San Diego (Bruehler and de Peyster 1999), which might make them more susceptible to botulism and other diseases, but no causal relationship has been established. A 1995 US Fish and Wildlife Service study attributed a 4% reduction of reproductive success of black-necked stilts to elevated concentrations of Se and worried that desert pupfish reproduction might also be affected (*Los Angeles Times* 25 April 1995). This does not seem to have actually occurred.

Se in Salton Sea sports fish (bairdiella, orangemouth corvina, sargo, tilapia) taken near the mouth of the Alamo River were higher than concentrations from fish taken upstream in the river, but usually not higher than public health criteria. One composite sample of orangemouth corvina had a concentration of 20 mg Se g^{-1}, considerably higher than the value reported by the state in 1986 and 10 times the "level of concern" in the state's health advisory (see below). Tilapia from drains ranged as high as 17 mg Se g^{-1} (Alamo River delta), a value considered detrimental to reproduction in fish-eating birds and higher than in other fish in these drains. The highest Se concentrations in mosquitofish and sailfin mollies came from populations in San Felipe Creek, which receives no irrigation wastewater (Saiki 1990; Imperial Irrigation District 1994; Setmire and Schroeder 1998).

In 1986, the California Department of Health Services announced that analyses of "edible flesh" from all four species of Salton Sea sport fish "indicate the presence of selenium at concentrations sufficiently high to warrant issuance of a health advisory for people who consume these fish." Reported Se concentrations ranged from 1.7 to 3.8 mg g^{-1} dry weight based on single tests of composites of 5 to 6 individual fish per species, effectively a sample size of one for each type of fish. Although there is no officially set public health standard for Se, the Department of Health Services regarded 2 mg g^{-1} dry weight Se as representing a "level of concern" with respect to human consumption. The health advisory stated that total consumption of any of the four fish should not exceed one 124.4 g portion in two weeks and that fish consumption should be avoided altogether by women of childbearing age and children under 15. Many residents, fishers, and biologists regarded with skepticism both the timing of this health advisory and also the data upon which it was based (Pomona CA *Progress Bulletin* 4 July 1986), as the advisory coincided with requests by the Imperial Irrigation District and Metropolitan Water District effectively to abandon the Salton Sea as a fishery

resource in favor of its continued use as an agricultural wastewater sump. No cases of human Se poisoning have been reported from eating Salton Sea fish (Salton Sea Authority and US Bureau of Reclamation 2000a). Now 20 years old, the health advisory has not been lifted, despite more recent data that suggest that it is unnecessary.

Methods to control Se in the Salton Sea watershed would be most effective if they dealt with Se at its point of highest concentration—subsurface agricultural drains (tile drains), which provide about a third of the flow in Imperial Valley surface drains. Se in tile drain waters is diluted by tailwater and leakage from canals so that the overall average of drainwater is diluted by ~67%. Some methods effective in preventing pesticides from entering drains also reduce the amount of tailwater. Since tailwater is an important source of relatively low Se waters, removing it from the drains may cause overall Se concentrations to increase (California Regional Water Quality Control Board, Colorado River Basin 1991).

Setmire et al. (1990) concluded that some as-yet-unknown mechanism in the Alamo and New River mouths was removing Se from the water and concentrating it in Sea sediments, which they said is the first step in incorporation of Se into Salton Sea food webs. Se can be metabolized by benthic bacteria and sequestered in sediments, such as flocculated silts that precipitate at the mouths of the New and Alamo Rivers (Postma 1967); the sediments of river mouths at the Salton Sea are a Se sink, receiving Se at a rate of 9 to 10 metric tons per year, one of the the largest known Se sinks in the world (Cagle 1998). Dredging sediments for dikes could resuspend this sequestered Se and so adversely affect Salton Sea food webs (Cagle 1998). Similarly, should the Salton Sea become significantly lower in elevation, these silts, now exposed to air, could lead to Se-enriched particles readily moved by winds.

Bacteria can reduce Se to selenite or hydrogen selenite—less soluble than selenate; much of the reduction in concentration of Se in the Salton Sea (as compared with drain and river water) might be attributed to this cause (Cagle 1998; Salton Sea Authority and US Bureau of Reclamation 2000a; Schroeder and Orem 2000). Incorporation of Se into organics may be capable of volatilizing Se or precipitating Se with organic detritus (Salton Sea Authority and US Bureau of Reclamation 2000a), though Schroeder and Orem (2000) concluded that atmospheric loss is not now important.

Other trace elements.—Values for most other trace elements in Salton Sea sediments are usually within baseline ranges (Setmire et al. 1990; Imperial Irrigation District 1994; Holdren 1998; LFR 1999; Setmire 2000; Schroeder and Orem 2000). According to LFR (1999), Bechtel National Inc. in 1997 studied contamination at the closed Salton Sea Naval Test Base. An aeroballistic target area in the Sea had been used for testing atomic weapons in the 1940s through 1960s, with ~3750 test units (non-explosive, non-radioactive) dropped—stainless steel casings filled with arming, fusing, and firing components, including lead/acid (until the 1950s) and nickel/cadmium (after the 1950s) batteries, and minor amounts of aluminum (Al), copper (Cu), brass, rubber, concrete, and lead or stainless steel ballast. These test units usually broke apart on impact, scattering debris over wide areas. Approximately 4545 kg were recovered from one area, but much debris still remains. A MK-6 "fly-around" radioactive test unit with 55

kg uranium (U) was lost in the Sea. No systematic attempt has been made to decontaminate this aeroballistic site. According to LFR (1999), Bechtel National in 1997 found somewhat elevated concentrations of antimony (Sb), arsenic (As), cadmium (Cd), Mo, Se, U, and vanadium (Va) at this site, but concluded that these elements were naturally occurring except for Cd, and that in view of the low concentrations, no additional actions need be taken.

Boron (B) concentrations in water and sediments were high enough to cause reproductive impairment in birds, though there have been no reports of avian developmental abnormalities at the Salton Sea. In several studies summarized by the Imperial Irrigation District (1994), B was elevated only in pileworms. Other invertebrates had concentrations at or below background. Salton Sea water had concentrations only slightly over the 10 mg B l^{-1} considered safe. Summarized analyses for fish reported 25 μg B g^{-1} dry weight in mosquitofish, similar to values at Kesterson in 1985. Salton Sea bairdiella had 5 to 8.3 μg B g^{-1} dry weight as did freshwater fish taken from rivers and drains (Imperial Irrigation District 1994). Some birds had elevated concentrations of B, chiefly those that feed on vegetation such as filamentous algae, though Setmire et al. (1993) speculated that piscivores might also accumulate B. The important conclusion is that boron is not a problem at the Salton Sea.

Elevated concentrations of chromium (Cr), nickel (Ni), and zinc (Zn) were found in Whitewater River sediments; Setmire et al. (1990) asserted that these concentrations were not associated with agriculture. Numerically, Setmire's (2000) results were similar to Setmire's study of 10 yr earlier. Over 25 trace metals have been detected in the New River at the international boundary. Those that exceeded federal standards in at least one sample were Ag, As, B, barium (Ba), Cd, Cr, Mn, Ni, lead (Pb), Se, thallium (Tl), U, tungsten (W), and Zn (Setmire et al. 1990; Setmire et al. 1993; Setmire 2000). Bradford et al. (1990) found no elevation in Salton Sea water concentrations of U, V, or Mo. Hg concentrations were elevated in fish-eating birds. Vogl et al. (2000) found somewhat elevated concentrations of Cd, Cu, Mo, Ni, Se, and Zn, with Mo and Se most elevated, particularly in the northern Salton Sea. These elements were also elevated in the top 0.3 m of sediments. Vogl et al. (2000) also detected very low concentrations of a number of volatile organics, which they concluded were the result of ordinary biological processes in the Sea. Again, the important conclusion is that trace element contamination is not a problem at the Salton Sea.

Only a few studies have looked at how Salton Sea biota take up trace metals. In laboratory experiments, the detritus feeder *Nereis succinea,* the herbivore and carnivore *Trichocorixa reticulata,* and the zooplanktivore *Balanus amphitrite* obtained trace metals, including Se (as selenate), from their food, not from the water column (Thomas et al. 1999; Wang et al. 1999a,b,c). Fialkowski and Newman (1998) analyzed seven trace metals in Salton Sea *Balanus amphitrite,* finding that concentrations both in brooded lipid-rich eggs and in adults varied between collection sites and were least where organic inputs were highest; concentrations were lower, sometimes markedly so, than in an estuarine population in Mission Bay, San Diego. They concluded "that the [Salton Sea], contrary to expectations, has not been severely contaminated by heavy metals." J. P. Skrupa of the US Fish and Wildlife Service is quoted in a recent undated handout from the Salton

Sea State Recreation Area as saying, "No human health problems have been noted from eating Salton Sea fish."

Other pollution issues.—In 1999 a proposal was put forward to import some 7730 metric tons of Hg-rich toxic sludge from Taiwan which had been illegally dumped in Cambodia, and to dump it in a 640 acre toxic waste site owned and operated by Safety-Kleen near Westmorland in the Imperial Valley. Vertical permeability of the deep Colorado River sediments in the Imperial Valley is not high (Hely et al. 1966; Layton and Ermak 1976; Salton Sea Authority and US Bureau of Reclamation 2000a), but with the proximity of this dump to the New River, it is still easy to imagine waste Hg seeping first into the New River and then being carried to the Salton Sea. In April 1999 the US Environmental Protection Agency rescinded its tentative approval for dumping this Taiwan/Cambodian waste (*Los Angeles Times* early April 1999). Residents of nearby Westmorland were elated. But what is the fate of other toxic wastes dumped in this site?

It was discovered in 1999 that Inland Container Corporation (now Inland Paper Board and Packaging) of Ontario CA was the source for illegal dumping of around 4545 metric tons of industrial wastes (shredded plastics, cellulose fibers) in "former wetlands" in the Coachella Valley adjacent to the Salton Sea. If these wastes had entered the Sea, the cellulose would be degraded by bacteria and fungi while lowering the concentration of O_2, and the undegradable plastic particles would cause serious problems for any fish or birds that ingested them, and perhaps also for some invertebrates. The actual dumper was a sub-contractor, two of whose employees were convicted and sent to prison for thirty months each. Inland Paper Board and Packaging volunteered to pay around $1 million to clean up the mess, and is suing to get repayment from both the contractor and sub-contractor (*Los Angeles Times* 14 December 1999; D. Reynolds and S. Householder pers. comm.). This incident serves as a warning about the perennial dangers of illegal dumping at the Salton Sea and adjacent wetlands.

The first part of a major study of the Salton Sea authorized by Congress in late 1998 was released in May 1999 by the Salton Sea Authority. Local newspapers (*Los Angeles Times* 23 May 1999; Ontario CA *Inland Valley Daily Bulletin* 24 May 1999) exulted over the good news. Because of negative publicity about contamination over the past several decades, the Salton Sea Authority had expected to "find elevated concentrations of pesticides, herbicides and metals, but we instead found almost no trace. This is good news." Executive Director Kirk of the Salton Sea Authority was quoted, "Despite popular conception, the Salton Sea is not dead." There was no explanation of why Director Kirk thought the Salton Sea should have been "dead," as all evidence indicated that this hypereutrophic lake was biologically flourishing (see above). The *Los Angeles Times* concluded, "If the Salton Sea is not a cesspool of pesticides, it could mean that cleaning up the sea, which will be a difficult, dirty and expensive undertaking, may not be as daunting as once feared." Then-Interior Secretary Babbitt was quoted, "The sea is much more vibrant and complex than people have thought."

The Salton Sea Authority's May 1999 report suggested that the shallowness of the sea and the turbulence kicked up by desert winds serve to dilute incoming pesticides. Much more likely, pesticides, trace elements, and other contaminants flowing into the Salton Sea are associated with clay particles, which in fresh water

are repelled from each other by negative charges and so remain in suspension. These clay particles flocculate and settle out as benthic sediments when the negative charges are neutralized by the higher salt concentrations of the Salton Sea, just as in conventional estuaries elsewhere (Postma 1967).

Overall, it appears that Jim Matthews (Ontario CA *Inland Valley Daily Bulletin* 3 June 1999) was correct when he alerted fishers: "Don't worry about the water (it's cleaner than Santa Monica Bay), and the fish are fine to eat."

Public Health

Popular accounts often worry that the Salton Sea and its inflowing rivers and drains are a source of major public health problems, such as sewage pollution and concomitant pathogenic fecal bacterial and viruses, industrial pollution that puts toxic trace elements into the Salton Sea (see above), and agricultural pollution with pesticides (see above), as well as other possible pathogens. Potential routes of transmission to humans include inhalation into the lungs, ingestion into the gut, skin contact, vectors, trauma, and physiological stress. So far, none of these has proved to be at all dangerous to human health, as concentrations of all potential pathogens and toxic substances turn out to be very low in the Salton Sea and its biota, including edible fish (though sometimes high in the New River and other agricultural wastewaters, see above); infested or infected humans have not been reported. Known pathogens of Salton Sea birds, such as Newcastle virus and the bacteria of avian cholera and avian botulism, do not usually affect humans (see above). *Vibrio vulnificus* is present in sick and dying Salton Sea fish, and though it can cause sometimes severe disease in humans, does not seem to have done so at the Salton Sea (Salton Sea Authority and US Bureau of Reclamation 2000a).

Mandated regular tests for coliform bacterial concentrations—an index of fecal and sewage contamination—rarely exceed minimum criteria for concern, though they can be high in the New, Alamo, and Whitewater Rivers (Salton Sea Authority and US Bureau of Reclamation 2000a). The usual test does not distinguish between fecal coliforms from humans and those from domestic and wild birds or mammals. The New River is well known for high pathogen counts at the international border, often greatly in excess of US standards (Setmire 2000). The source is probably Mexicali, which lacks a viable sewage treatment system. Pathogens recovered from New River water in Calexico include the bacteria responsible for "food poisoning" gut infections (*Salmonella* spp., *Shigella* spp.), typhoid (*Salmonella typhi*), *Aeromonas* spp. and cholera (*Vibrio cholerae*), as well as the viruses that cause meningitis. There are no positive records for other human bacterial and viral pathogens, either in the New River or in the Salton Sea (*Los Angeles Times* 4 November 1995; Wolcott and Berlowski 2000). Many illegal immigrants swim the New River to enter the US where there is a break in the 3.5 meter border wall at Calexico, hiding in foam patches and "often" suffering illness from drinking the foul water (Ontario CA *Inland Valley Daily Bulletin* 30 January 2000).

Fecal coliforms and streptococci which have been consistently detected at the international boundary are killed or diluted by the time New River water reaches the Salton Sea (Salton Sea Authority and US Bureau of Reclamation 2000a). Coliform bacterial counts at the mouth of the New River and in the Salton Sea

are usually below concentrations considered hazardous for humans (Riverside County Health Department, no date), though in the 1960s Imperial County posted ~5 km of the Salton Sea shoreline from the New River mouth north to Bombay Beach as "unfit for water-contact sports," and Riverside County similarly posted an area near the mouth of the Whitewater River (US Department of the Interior and The Resources Agency of California 1969, 1974a,b). Coliform bacteria in the Salton Sea itself are unlikely to be of human origin, but more likely to be from the many water-related birds. One would not expect significant sewage contamination of the Salton Sea, since its periphery is so sparsely populated. The Salton Sea is a Class I water, suitable for body contact.

Mosquitoes carry a number of arboviruses, including those causing western equine encephalomyelitis (Togaviridae) and St. Louis encephalitis (Flaviviridae). These encephalitis viruses have been detected in Salton Trough mosquitoes, *Culex tarsalis* and *Aëdes dorsalis,* but not in humans. The last known human case of western equine encephalomyelitis in the Trough, which was fatal, was in 1938 (Coachella Valley Mosquito and Vector Control District 1997; Salton Sea Authority and US Bureau of Reclamation 2000a), but 2% to 16% of current residents who visited clinics and hospitals for any reason had antibodies to one or both encephalitides, though they had not been sick (Reisen et al. 1996). Both viruses maintain a primary enzootic transmission cycle involving wild birds and mosquitoes, but mammals are also infected. Vector mosquitoes, primarily *C. tarsalis,* breed in marshes in the Coachella Valley and elsewhere and may often be abundant, especially from late spring through early autumn, with the most cases in August and September (Reisen and Lothrop 1995; Reisen et al. 1995, 1998; Coachella Valley Mosquito and Vector Control District 1997; Oglesby pers. obs.). Species, unidentified, of culicid larvae and pupae have been found in the concrete-lined Cleveland Street Spillway, Whitefield Creek, and shoreline pools (Table VII). There have been reports of encephalitis-infected mosquitoes in the southern Imperial Valley and even one unconfirmed human case associated with the New River (Cagle 1998).

All species of *Anopheles* mosquitoes are vectors for malaria, once common throughout California. Several species of *Anopheles* have been reported from the Salton Trough (Mullens and Dada 1992; Reisen et al. 1999), but no recent cases of malaria are known. But a traveler or immigrant who contracted malaria elsewhere and who relapsed from *Plasmodium vivax* could lead to a localized indigenous outbreak, as has been documented several times in immigrant camps and adjacent communities in San Diego County and the San Joaquin Valley, as well as in a Girl Scout camp in the Sierra Nevada (A. Oglesby pers. comm.). Humans have recently changed their habits, reducing their exposure to vector mosquitoes; they stay indoors at dusk watching television, rather than being bitten by (infected) mosquitoes while outside (A. Oglesby, pers. comm.). Nevertheless, the potential exists for a malarial outbreak at any time.

Both species of the prosobranch snail *Thiara* are intermediate hosts for a diversity of digenetic flukes in both the Old and New Worlds, including some serious human parasites. For example, *T. tuberculata* in Visakhapatnam, India, harbors 19 species of larval trematodes from 10 families (Madhavi et al. 1997). In many parts of the world including the Salton Trough, both thiarids and parasites are introductions. Larvae of the digenetic trematode *Paragonimus* sp. (lung fluke)

were found infesting one specimen of *T. granifera* from Whitefield Creek in the summer of 1988 (Oglesby pers. obs.). *P. westermannii* is a serious human parasite common in much of southern and eastern Asia and adjacent Pacific islands. The life cycle of *P. westermannii* involves a carnivorous mammal (humans) in which flukes reach sexual maturity in the lungs and release eggs which enter the esophagus and are eliminated with feces. Eggs hatch into swimming miracidia larvae which enter freshwater snails (*T. granifera* and other gastropod species in Asia: Davis et al. 1994) as first intermediate host. Swimming cercarial larvae emerge from snails after significant asexual reproduction in the snail's digestive diverticulum and gonads, and enter a large crustacean (freshwater crabs in Asia) as second intermediate host, which is then eaten uncooked by the human host-to-be (Noble et al. 1989).

Both *Thiara granifera* (first intermediate host) and Louisiana red crayfish (potential second intermediate host) co-occur in agricultural drains and springs around the Salton Sea (Tables VI, VII), but it is unlikely that enough humans (potential definitive host) eat raw crayfish and then defecate into these waters to maintain a parasite life cycle involving humans. More likely, the definitive mammalian host of this as yet unidentified species of *Paragonimus* is a local carnivore such as raccoon, kit fox, or coyote (Noble et al. 1989; Oglesby pers. obs.). A New World human lung fluke, *Paragonimus mexicanus,* afflicts freshwater crab-eaters, and has been found in desiccated pre-Colombian mummies in Central America (Pringle 1998).

The San Antonio Zoo, Texas, populations of both *Thiara granifera* and *T. tuberculata* harbor rediae and release cercariae of *Philophthalmus megalurus,* an eye fluke which infests nictitating membranes of birds and occasionally mammals. There are a few known cases of human infestation with eye flukes in Asia, but none yet known from the US. The entire life cycle operates at the San Antonio Zoo, with the definitive hosts there being waterfowl (Murray and Stewart 1968; Murray and Haines 1969; Murray 1971b; Kotrla 1975, 1977, 1983; Kotrla and Murray 1980). Alicata (1962) described in detail the life cycle of another avian eye fluke, *P. gralli,* whose host is *T. granifera* in Hawai'i.

Thiara tuberculata is an important intermediate host in Asia for the Chinese liver fluke *Opisthorchis sinensis.* Many species of fish, including poeciliid fish such as sailfin mollies which are abundant in the Salton Trough serve as second intermediate hosts (Dundee and Paine 1977). Dundee and Paine (1977) worried that all species involved in the Chinese liver fluke life cycle were present in Louisiana, including Southeast Asian immigrants who may have brought the flukes with them and who eat raw fish. The same would be true in the Salton Trough. McCullough and Malek (1984) concluded that establishment of a human Chinese liver fluke life cycle was unlikely in Louisiana, but stated that not enough information was available to be certain. A population of *T. granifera* was found in Echo Park Lake in Los Angeles, which was then drained and the snails eliminated because of worry about human parasites (C. Coney, pers. comm.).

Another introduced human parasite life cycle might be present in the Salton Trough. Basch et al. (1975) found the snail *Biomphalaria obstructa* in the Coachella Valley in the Avenue 82 drainage canal near Oasis (Table VI). *B. obstructa* is a first intermediate host for the blood fluke *Schistosoma mansoni,* whose cercariae infest humans after burrowing into the skin. A Yemeni strain of *S. mansoni*

was raised in Salton Trough *B. obstructa* in the laboratory (Basch et al. 1975). About 50% of Yemeni agricultural workers in the San Joaquin valley were infected with *S. mansoni* in 1972. None of 100 *B. obstructa* collected from the Coachella Valley harbored schistosome rediae or cercariae, so it is unlikely that the parasite life cycle is now established in the Salton Trough (Basch et al. 1975). Furthermore, since both species of *Thiara* can outcompete several species of *Biomphalaria* and thus have reduced or eliminated schistosomiasis on several Caribbean islands (Giboda et al. 1997), the spread of *B. obstructa* in the Coachella Valley may be severely restricted.

As Cohen et al. (1999) observed, protecting public health is not a component of any current Salton Sea "restoration" plan (e.g., Salton Sea Authority and US Bureau of Reclamation 2000a).

Cleaning up the New River

Many serious human pathogens and other potentially harmful substances have been found in the New River at the international boundary (see above). Abundant foam at the border is caused by detergents, and often contains high fecal coliform and *Streptococcus* concentrations (see Moore [2000] for color photos of New River trash). Large floating patches of foam can be seen north of Calipatria, downstream, where the New River falls over a small weir (Oglesby pers. obs.). Curiously, the New River at Calipatria is no longer signed about pollution.

Trace element and pesticide concentrations in the southern, upstream, part of the New River are high. Comparisons with contaminant concentrations in Salton Sea biota show that the latter may contain low concentrations of some pesticides and trace metals, but not high enough to cause adverse health effects from eating either New River or Salton Sea biota. However, the Public Health Service recommends that no one eat anything from the New River because of its many human pathogens (US Public Health Service Agency for Toxic Substances and Disease Registry 1996).

Because of its notorious contamination, plans have been developed to "clean up" the New River, potentially the largest point source of pollutants to the Salton Sea, and one of the most polluted rivers in the US. A pact was signed in January 1987 between the US and México, pledging US dollars to help build a sewage treatment plant for Mexicali (population ~800,000 to 1 million), most of whose untreated sewage is now discharged directly into the New River just before it enters the US. Congress appropriated $5 million for a dozen "quick fix" repairs to the Mexicali sewer system, and $47.5 million was allotted to the International Boundary and Water Commission for anti-pollution efforts along the border, with much of that US sum being proposed to build an entirely new Mexicali sewage system (*Los Angeles Times* 4 November 1995, 7 August 2000; *Time* Magazine 20 April 1987; Anonymous 1989; Fortner 2000; *USA Today* 11 May 2000; Moore 2000).

Additionally, a New River test purification project (New River Wetlands Project), under the auspices of a Citizen's Congressional Task Force guided by the California Department of Fish and Game for 12 federal, state, and county agencies and legislators, is being constructed at a site ~8 km downstream (northwest) of El Centro (Moore 2000). Low levees will force New River water to spread into two marshy ponds constructed adjacent to the river. The first pond is for silt

settlement, the second for wetland treatment of organic pollutants, lowering nutrient concentrations in water to be returned to the New River. Monitoring will be by the Imperial Irrigation District. US Bureau of Land Management biologists estimated that 4.2 km of marsh land flow would clean the river entirely, but due to the New River's extreme concentration of pollutants, the project allowed for >8 km of marsh flow before the river enters the Salton Sea. Costs are expected to be modest. If the current pilot project is effective, plans call for 40 two-pond purification wetlands to be constructed along the entire lengths of both the New and Alamo Rivers, including a 121–152 ha site just downstream from Finney and Ramer Lakes on the Alamo River. It is expected that these ponds will develop into new wetlands valuable for wildlife and increased hunting, fishing, birding, and other forms of recreation (*Los Angeles Times* 7 August 2000; Moore 2000).

Nothing is being done to allay trace metal and human pathogen pollution from Mexican domestic sewage, industry, and *maquiladoras* (Anonymous 1989). The New River at Calexico is anoxic, hence there are no fish (*Los Angeles Times* 7 August 2000).

Detoxification now occurs as the New River travels the 96 km from Calexico to the Salton Sea, so that river water entering the Salton Sea is nowhere near as polluted as it is in Calexico. The 1974 Feasibility Study discussed bacterial concentrations in the Salton Sea, but presented no data (US Department of the Interior and The Resources Agency of California 1974a,b). Federal and state testing programs continue to reveal the magnitude of the New River pollution problem, and official concern has increased since ratification of the North American Free Trade Agreement. Lawsuits are threatened by Imperial County against the US Environmental Protection Agency, which has recently become more aggressive in dealing with the New River. But the remoteness of the Imperial Valley to Washington DC, its sparse population (only ~130,000 people in 2000), and federal, state, and local budget problems all conspire to limit effective actions. Imperial County Supervisor Van De Graaff said in 1995, "When all is said and done about the New River, there's been a lot more said than done" (*Los Angeles Times* 4 November 1995.)

Energy Development at the Salton Sea

Geothermal energy.—The Imperial Valley and Valle de Mexicali are valuable for geothermal energy development because of high temperature groundwaters near the surface, associated with the northernmost two of the East Pacific Rise crustal spreading centers, the Brawley Seismic Zone and Cerro Prieto. The first geothermal wells in the Salton Trough were developed in 1927 and 1928 at Mullet Island (California Department of Water Resources 1970; Lande 1979), but were soon abandoned. Drilling east of Mullet Island again took place in 1933 through 1954, but was equally unsuccessful (Sturz et al. 1998). After two successful test wells were drilled in 1957 and 1958 near Red Hill and Alamo Butte, geothermal explorations began in earnest and still continue for ways to exploit geological heat for production of electricity (Shinn 1976; Lande 1979; Black 1981). The nine geothermal plants in the Imperial Valley produced 380 megawatts (MW) in 1999.

Discharge of geothermal waste brines to the Sea is prohibited by the California Regional Water Quality Board Colorado River Basin Region (Resolution No. 63–

14 and later resolutions). Nevertheless, spills do occur. In April 1976 geothermal wastes in an evaporation pond spilled into a drain near Red Hill Marina, causing a large kill of otherwise healthy orangemouth corvina both in the drain and the adjacent Salton Sea (Phelps and Anspaugh 1976; R. Ireland, pers. comm.). At a 1981 US Bureau of Land Management hearing on proposed oil and gas leases (see below), the Union Oil District Operations Manager strongly denied the fact of any such spill (pers. comm.). Later R. Miller (pers. comm.), Imperial County Planning Director, wrote that Imperial County, the California Division of Oil and Gas, and the Department of Fish and Game "had no record of any spills contaminating the Salton Sea," but went on to say that there are "some unofficial personal accounts" that a holding pond leaked into a drain, and that two other wells "as a matter of normal operations, discharged some of their fluids into the drain system and thus into the sea." R. Zortman (pers. comm.), El Centro Resource Area Manager, US Bureau of Land Management, wrote, "The fish kill identified in your letter was the result of flow testing of the geothermal resource." In other words, the spill and associated orangemouth corvina kill did not happen, but the spill and resultant fish kill were the result of normal operations. Whether or not this 1976 fish kill really took place (I am sure that it did.), it and many endangered green sea turtle (*Chelonia mydas agassizii*) deaths in Laguna Ojo de Liebre from a spill of salt works brine in December 1997 (A. Hershowitz, pers. comm.) serve as warnings that brine spills, whether from geothermal energy development or other diked evaporation ponds (see below), could seriously damage the biota of the Salton Sea.

At several locations in the volcanic buttes area geothermal facilities have been developed, cooperative ventures of private energy companies and the US Department of Energy. Unlike the Geysers facility north of San Francisco (one of two other geothermal facilities in California) with its energy source clean superheated steam, underground temperatures in the Salton Trough are lower, from 61°C to over 260°C (Boardman 1998a). Geothermal fluids in the Imperial Valley are among the most saline natural liquids known, from 200 g l^{-1} to as high as 330 g l^{-1}, and have high concentrations of trace metals (White et al. 1963; Phelps and Anspaugh 1976; Helgeson 1968; Lindsay and Hample 1998). Imperial Valley drill depths vary from ~750 to 1000 m to as deep as ~2470 m. High salinities cause continuing problems of corrosion of metal fixtures and brine disposal (Shinn 1976). Injection of waste brines into the ground is now used for disposal, a practice which helps avert soil subsidence and which should also avert damage to aquatic biota. If brine spills can be controlled, environmentally the greatest problem may be negative interactions between the festoons of high-voltage power lines and migratory waterbirds (Leitner and Grant 1978). Layton (1978a,b) and Black (1981) worried that the necessary utilization of fresh water by geothermal facilities would reduce water inflow to the Salton Sea and thus exacerbate Salton Sea salinity problems.

In 1983 the California Department of Fish and Game authorized the Bear Creek Mining Company to use >50% of the Wister Unit of the Imperial Wildlife Area for geothermal energy exploration. Much concern was expressed about the adverse effects of geothermal drilling in a wildlife refuge, both as to direct effects of noise and light disturbance on nesting of the endangered Yuma clapper rail and other birds, and effects of spills of hot geothermal brines into managed wa-

terfowl ponds. But a Department of Fish and Game geothermal expert defended this permission: "To put it simply, we decided it was safer to have them inside the refuge—where we could control them—than to have them outside. This way we can tell them exactly how to run their operation, and we can shut them down when we need to" (*Los Angeles Times* 10 June 1983; F. Worthley, pers. comm.).

In 1982, Imperial County authorized 44,922 ha for geothermal energy development. Actual production has gone from a single 10 MW facility in 1985 to >380 MW from nine facilities in 1999 (*Los Angeles Times* 24 January, 2000). By 1990, at least 60 production wells and hundreds of exploration wells had been drilled (Norris and Webb 1990). The Imperial Valley, the "Saudi Arabia of geothermal," is estimated to be able to support >1000 MW of electrical power production (US Bureau of Land Management *Newsbeat,* November–December 1995; Lindsay and Hample, 1998). See the books by Butler and Pick (1982) and Lindsay and Hample (1998) for detailed discussions of problems and prospects for geothermal energy development in the Imperial Valley.

Reprocessing technology is now used to salvage trace metals from Imperial Valley geothermal brines, reducing their environmental impacts. In September 1998 a contract was awarded for a $148 million plant to recover 27,300 metric tons per year of Zn. The plant was expected to be operational in mid-2000 (Premuzic et al. 1997; Kohler-Antablin 1999).

Solar ponds.—The Salton Sea has been proposed as the site of a solar pond for electricity generation. In 1980, a pilot solar pond project was proposed for the Navy's Salton Sea Test Base, using Israeli technology and starting with a 5 MW plant that would cost $20 million. At that price, 1 kilowatt (KW) would cost $4000 in 1980 dollars, about twice that of now-uneconomic nuclear power plants. Promoters hoped that future solar ponds could generate electricity at one-third to one-fourth this initial cost. If the pilot experiment is successful, a solar pond of around one-fourth the area of the entire Sea is envisioned, located at the shallow southern end (Black 1981; WESTEC Services 1981). No solar pond has yet been constructed.

Manure energy.—Feed lots in the Imperial and Coachella Valleys accommodate ~450,000 cattle (*Bos taurus*), primarily in the winter as cattle have a difficult time during intense summer heat. A single cow can drop 680 kg manure yr^{-1}, a total of ~31 million kg yr^{-1} for the Salton Trough. Cattle manure is a significant source of phytoplankton nutrients in the New and Alamo Rivers and thus of the Salton Sea. Beginning in 1988 Phillips Cattle Company in El Centro operated a $47 million experimental plant which burned cattle manure for electricity, offering a seemingly practical solution as to what to do with all that dung. This manure plant ground to a sticky halt in torrential rains in 1993, and the plant switched to more expensive natural gas. In 1994 the US Energy Commission denied an appeal from Phillips, which in effect prevented the manure electricity plant from starting up again unless the company repaid some $6 to $9 million to Southern California Edison. A 26 February 1994 *Los Angeles Times* news item suggested that the manure plant might go bankrupt if forced to repay all this money in a lump sum. What else can be done to rid the Salton Trough of so much manure, which contaminates surface and groundwaters with phytoplankton nutrients and organics whose decomposition lowers O_2 concentration, and stimulates growth of bacteria?

Other energy proposals.—The Salton Sea has been studied by the US Bureau of Land Management for natural gas and petroleum production using both onshore wells and offshore artificial "islands" (*Los Angeles Times* 13 March 1981; US Bureau of Land Management 1982). The Bureau, after preparing an inadequate Final Environmental Assessment and after holding a 1981 public hearing in which nearly everyone spoke in opposition (US Bureau of Land Management 1982; US Bureau of Land Management Decision Option Document 10 June 1982; Matthews 1982; Oglesby pers. obs.), authorized 57 noncompetitive leases to Chevron, but no drilling has yet taken place. The controversy over these proposed leases immediately led to the formation of the Salton Sea Fish and Wildlife Club, a group of fishers and residents who advocate preservation of the integrity of the Salton Sea ecosystem and its fine sport fishery (*Los Angeles Times* 13 March 1981).

No one state or federal agency coordinates these and other energy explorations and developments in and near the Salton Sea. No proposal analyses cumulative effects of these diverse energy developments. All energy developments are vulnerable to earthquake damage, particularly those involving evaporating brines stored in diked ponds. Earthquake-damaged energy facilities and broken dikes might well send toxic materials or brines into the Salton Sea. Even if dikes were not breached, earthquake-generated seiches in brine ponds might cause saline water to overtop the dikes and enter the Sea.

Water Politics and the Salton Sea

"Water is the life blood of California politics," goes a popular saying. The Salton Sea and its remarkable sport fishery have little impact on water politics in California. Fishers are for the most part lower-income families from urban southern California (in 1982, 42% were from Los Angeles County) and have limited political clout. "The Salton Sea is the resort of the ghetto," wrote R. A. Jones in the *Los Angeles Times* (23 May 1989).

The Salton Sea itself has no priority to receive water from any source. Drainage and seepage waters that maintain the Sea are officially incidental results of other "beneficial" uses of water, governed by compacts, agreements, court decrees, and federal and state laws (US Department of the Interior and The Resources Agency of California 1969). The Imperial Irrigation District and Coachella Valley Water District, whose water goes primarily to agriculture and ultimately into the Salton Sea, and the Metropolitan Water District which pumps Colorado River water to urban and suburban communities (but little to agriculture) from San Diego to Santa Barbara and from the coast inland to San Bernardino and Riverside, are politically powerful and have a profound interest in keeping the Salton Sea as a sump for wastewater.

"During modern times, uses and control of water still inspire more vocal violence, legal controversy, editorial polemics, and political rhetoric than any other subject," wrote Gulick (1991) about the Snake and Columbia rivers in the Pacific Northwest, but he could equally well be describing the Colorado River. He continued, "Two basic assumptions were treated as sacred: the first, that dams meant progress; the second, that irrigation rights exceeded all others."

Swajian (1976) says of the Colorado River basin region: "Agricultural interests take the position that there was literally no aquatic habitat in these valleys prior to the advent of irrigated agriculture; that the agricultural drainage systems were

developed as a necessary means of surface and subsurface drainage to maintain soil-salinity control; that it is by virtue of agricultural funding and development that the aquatic habitats exist; [and] that any aquatic or wildlife resources associated with the drains are at most corollary benefits of the primary purpose of these drains."

This widely held belief that the aquatic and riparian ecosystems of the Salton Trough are totally artificial and so are of reduced or no biological value ignores the fact that the extensive and productive riparian forests, lagoons, sloughs, and wetlands of the broad Colorado delta in México have been almost totally destroyed by the diversion of Colorado River water upstream from Morelos Dam (1.6 km south of the international border), primarily for agriculture in the Salton Trough (Sykes 1926; Kniffen 1932; Leopold 1949; Fradkin 1981; *Los Angeles Times* 26 December 2000). Since completion of Morelos Dam in 1950 and diversion of water into the Canal Central to irrigate the Valle de Mexicali, the Colorado River now disappears completely within a few km downstream of the dam—"a river no more" according to Fradkin (1981)—only to reappear further south because of returned saline flows from Mexican agriculture. Colorado River water now rarely reaches the Gulf of California, leading to significant ecological changes in the northern Gulf and loss of important fisheries, including the near extinction of the totoaba, the world's smallest porpoise, the vaquita (*Phocoena sinus*), and an important shrimp fishery in the northern Gulf (Hendricks 1961b; Fradkin 1981; Weatherford and Brown 1986a; Mellink and Ferreira-Bartrina 2000). There was a 95% reduction in intertidal clam density in delta mudflats since Hoover Dam was closed in 1936, from 50 clams per square meter down to 3 per square meter (Kowalewski et al. 2000).

These formerly highly productive Colorado Delta wetlands supported a great abundance of resident and migratory wildlife that no longer inhabit the Delta; see Aldo Leopold's 1949 *A Sand County Almanac* for a fine description of the Delta in 1922. As deBuys (1999) and Mellink and Ferreira-Bartrina (2000) observed, even in 1922 much of the Delta was already severely degraded by US water diversions and developments in the early 20th century, and by increased siltation as a consequence of intensive trapping of the beavers (*Castor canadensis*) in the river during the 19th century. An overview of the recent status of Delta wetlands and riparian forests, and the northern Gulf of California, was given by Cohen et al. (1999) who concluded that there were still many hectares of high-quality wildlife habitat which would be adversely affected by any further reductions in Colorado River flows. By contrast, Mellink and Ferreira-Bartrina (2000) and the *Los Angeles Times* (26 December 2000) concluded that the many changes in favor of agriculture and the loss of Colorado River water—loss of the dense riparian forests, reduction and extinction of many native species, and introductions of alien species—have totally altered most of the delta, except for a few relict locations. Further diversions of water from the River, for whatever reason, would only worsen these problems in the delta (*Los Angeles Times* 26 December 2000).

Even in the pre-irrigation Imperial and Coachella Valleys there were riparian habitats along the rivers and a number of ponds and freshwater lakes, all host to water-related wildlife. Most of these aquatic systems vanished with the 1905 to 1907 overflow of the Colorado River into the Salton Trough, but others have been

remade into valuable aquatic habitats, including Finney and Ramer lakes (see above).

With the destruction of the vast Colorado River Delta wetlands in México, resident and migratory wetland birds now use the ecosystems of the Salton Sea and surrounding areas. One can view the Salton Sea and its adjacent riparian areas as partial substitutes for the loss of Colorado Delta wetlands. "The Salton Sea, despite its artificial genesis, serves as de facto mitigation on a regional if not continental scale for the 92 to 99% of wetlands that have been destroyed in the region" (Ornithological Council 1998).

It was only as recently as 1982 that the Salton Sea was officially recognized as having "unique and valuable fish and wildlife resources and associated recreational values" (California Fish and Game Commission 1982). The Commission, while continuing to designate the Salton Sea primarily "as a repository for agricultural drainage water," recommended policies to:

- Preserve the biological integrity of the Salton Sea and its associated wetland habitats.
- Protect and perpetuate the diverse fish and wildlife resources of the Salton Sea ecosystem for use and enjoyment of present and future generations.
- Prevent or alleviate those aspects of projects, developments, and activities which would or do exert adverse impacts on habitats and fish and wildlife resources of the Salton Sea ecosystem.
- Urge the formation of a multi-agency task force with instructions to prepare a program designed to stabilize Salton Sea salinity and elevation permanently at concentrations which will sustain and perpetuate existing fish and wildlife resources concomitant with energy development and related projects.

The Commission did not reconcile the contradictory nature of these goals.

The Colorado River is surely the most scrutinized, most controversial, most dammed, most regulated, most negotiated, most legislated, and most litigated river in the US (Hundley 1986)—"The River of Contention," according to former Interior Secretary Babbitt (*Los Angeles Times* 18 December 1999). According to the California doctrine of prior appropriation, the Imperial Irrigation District and the Coachella Valley Water District have prior water rights ("first in time, first in right") to Colorado River water over the Metropolitan Water District that provides domestic water to 16 million people in urban and suburban coastal southern California. The contradictory California doctrine of riparian rights, by which owners of land adjacent to a stream must be allowed to divert all the water they can practicably use, does not apply significantly in the Imperial and Coachella Valleys. However, a June 2000 decision by the US Supreme Court allowed the Quechan Indian tribe to pursue its claim to 79,000 acre-feet of Colorado River water if it could prove it owns 6178 ha along the River at its Ft. Yuma Reservation (*Los Angeles Times* 20 June 2000). Even though the amount of water involved is small, only ~1% of the River's average flow, that was not factored into the allocation of River water to the states and water agencies by the 1922 Colorado River Compact. Where will this additional water allotment come from?

Between 1961 and 1985, diversions into the Salton Trough by the Imperial Valley Irrigation District and Coachella Valley Water District averaged ~3.5 million acre-feet yr^{-1} (out of a total California allotment of 4.4 million acre-feet

yr^{-1}), with another 0.3 million acre-feet taken by water districts on the California side of the lower Colorado River (Parsons Corp. 1985). The Imperial Irrigation District has a "present perfected right" (meaning it must be supplied first in case of shortage) to 2.6 million acre-feet yr^{-1} of Colorado River water, but normally takes ~3 to 3.5 million acre-feet yr^{-1} (Imperial Irrigation District Public Information Office 1991). Of this amount, more than a third (~1.3 million acre-feet yr^{-1}) wind up in the Salton Sea (Parsons Corp. 1985).

Much of the agricultural production of the Imperial Valley consists of low-value but high-water-consuming crops such as alfalfa and cotton, rather than high-value and lower-water-requiring crops such as salad vegetables, citrus, tomatoes, and grapes. Even so, Imperial County agriculture was valued at ~$1.04 billion in 1997, based primarily on cattle, alfalfa, carrots, sugar beets, lettuce, hay, wheat, cantaloupes, and broccoli (Salton Sea Authority and US Bureau of Reclamation 2000a). Conversion of crops to less thirsty ones would release water for other uses and would provide more agricultural jobs since high-value crops are labor-intensive. But farmers point out that raising low-value crops allows farms to stay profitable even when prices drop, and that if everyone grew only high-value crops, prices would drop. Alfalfa, a legume, is important as a rotation crop in the Imperial Valley (Anonymous 1999). Agriculture in the ~15,321 ha cultivated in the Coachella Valley consists primarily of such high-value crops as grapefruit, lemons, cotton, dates, grapes, peppers, watermelons, carrots, and salad vegetables—valued at ~$332 million in 1997 (Nordland 1978; Salton Sea Authority and US Bureau of Reclamation 2000a).

Major conflicts arise during droughts over the "wastage" of agricultural water in the Imperial Valley at the same time as residents of metropolitan and suburban Los Angeles are under domestic water use restrictions. An important feature of California water law is that failure to use an adjudicated water right for beneficial use for five years can result in its loss ("use it or lose it"). Thus, a water district or utility must use all of its legal allotment or forfeit the excess over what it actually uses (Engelbert and Scheuring 1982). Many have accused the Imperial Irrigation District and the Coachella Valley Water District of wasteful practices just to seem to be using all their legal allotments (Engelbert and Scheuring 1982). This legal issue informs the controversy over proposals to market "excess" water from the Imperial Valley to San Diego, using Metropolitan Water District pipelines (*Los Angeles Times* 30 January 2000). There are also many serious international problems between the US and México over Colorado River water allocation and salinity issues. It was only as recently as 1972 that México was assured of not only 1.5 million acre-feet yr^{-1}, but that this water be of low enough salinity to be usable for agriculture (Holbert 1975; Fradkin 1981; Hundley 1986).

"Water in a transfer process is treated as a commodity, such as oil and gas, and sold to the highest bidder—a process that often assumes that Nature has no need for water" (Cagle 1998). A 1988 agreement between the Metropolitan Water District and the Imperial Irrigation District provides Metropolitan with "excess" Imperial water if Metropolitan lines 322 km of the All-American and Coachella Canals to prevent water loss by seepage, along with a number of other Metropolitan-financed projects (*Los Angeles Times* 13 November 1988; Breuer 1992). When canal lining is complete, Whitefield Creek, Salt Creek, and a number of other desert oases, springs, and seeps will surely desiccate, with loss of important

aquatic and riparian habitats and water for many desert mammals, birds, amphibians, fishes, invertebrates, and plants. In addition, as much as 80% of seepage water from the Coachella Canal may now enter the Salton Sea as low salinity groundwater; its loss would worsen the problem of the Sea's increasing salinity. Seventy-seven km of the Coachella Canal in the Coachella Valley itself have been concrete lined; the 61 km between Niland and North Shore along the east side of the Salton Sea were still not lined in 2000 (Layton and Ermak 1976; Pryde 1999; Coachella Valley Water District 2000).

Recent proposals by some Imperial Valley farmers to sell "unneeded" irrigation water to the Metropolitan Water District and the San Diego County Water Authority have created a storm of controversy within the Valley. One proposal by the Imperial Irrigation District calls for Metropolitan to compensate Imperial Valley farmers who voluntarily fallow a portion of their land, or do not water alfalfa for 75 days during the summer; this proposal might provide Metropolitan with as much as 100,000 acre-feet annually (*Los Angeles Times* 5 April 1999).

The Coachella Valley Water District asserts that the Imperial Irrigation District is taking more than its legal share of Colorado River water, which is complicating and delaying negotiations on the other issues (*Los Angeles Times* 6 September 1998, 5 April 1999).

A "truce" between the Metropolitan Water District, Imperial Irrigation District, and Coachella Valley Water District, mediated by California Governor Davis and the US Department of Interior, was announced in August 1999. The three water agencies agreed to accept less water than they contended they are legally allotted, to pay more for infrastructure than they contended they should, and promised not to file legal complaints against their rivals (*Los Angeles Times* 16 October 1999). The agreement permits sale and export of up to 200,000 acre-feet of water per year to the San Diego County Water Authority, delivered through the Colorado River Aqueduct owned by the Metropolitan Water District (see *Los Angeles Times* 30 January 2000 for a critical analysis of this specific transfer). Salton Trough farmers will use the money to increase irrigation efficiency and install additional water conservation procedures.

Under this agreement, California will gradually scale back its take of Colorado River water from its current 5.5 million acre-feet to its allotted 4.4 million acre-feet in 15 yr (*Los Angeles Times* 14 December 2000). Pomento (1998) wrote that this agreement would exempt the irrigation agencies as well as the Metropolitan Water District from liability for any damages to the Salton Sea that would arise from a reclamation plan or any other actions that would reduce inflow, including increased water conservation or export out of the Salton Trough to San Diego. With this agreement, it is unlikely that México will ever receive any "excess" water, thus degrading the delta's remaining wetlands even further (*Los Angeles Times* 26 December 2000). Commented the *Los Angeles Times* (5 August 1999), "What makes water disputes so intractable is the tendency of all parties to believe that they have been aggrieved by history and generally misunderstood."

At the same time, the International Boundary and Water Commission signed an agreement to authorize a $3 million study of the feasibility of building a joint aqueduct to bring Colorado River water to San Diego in California and Tijuana and Rosarito in Baja California (*Los Angeles Times* 17 October 1999).

Any of these proposals would reduce the amount of water entering the Salton

Sea (Parsons Corp. 1985), but rarely has anyone involved seemed to be concerned about the biology of the Salton Sea or maintaining its sport fishery. At the present time, ~1.3 million acre-feet are discharged into the Salton Sea annually, roughly matching annual evaporation. If all proposed water conservation and transfers are effected, this total will be reduced by as much as 775,000 acre-feet, reducing annual input to the Sea by well over one half (Horvitz 2000). Water conservation and transfers by the Imperial Irrigation District would lead to several adverse effects on the Salton Sea. These were listed in a 1986 environmental impact report (California Regional Water Quality Control Board, Colorado River Basin 1991):

- Decrease in use by terrestrial biota of Salton Sea aquatic and riparian habitats.
- Accelerated loss of biota, including sports fish, in the Salton Sea.
- Accelerated loss in the recreational value of the Salton Sea.
- Accelerated loss in resort and property values near the Salton Sea.

A few important people have paid attention. On 6 October 1997, the late Rep. George Brown (D-Colton CA), long-time Chair of the House Committee on Science, worried in a *Los Angeles Times* op-ed piece that if the major competitors for lower Colorado River water developed an agreement coupling both water conservation and water transfer, they would surely destroy the biology of the Salton Sea. Brown wrote: "If MWD [Metropolitan Water District] carries the day, it would reinforce its monopoly over wholesale water use in the region, provide a disincentive for agricultural water conservation, and, most disastrously, drive the Salton Sea ecosystem into rapid, total collapse. The Salton Sea is a beautiful oasis that must be saved. San Diego is entitled to seek more secure sources of water than MWD provides. Imperial Valley farmers should be allowed to craft a deal that rewards them for water conservation. If MWD wins this struggle, it will be a regional disaster and a national disgrace." But has anyone actually paid attention to the late Rep. Brown? The summer 1999 agreement suggests no. It remains to be seen whether the provisions of the new agreement will prevent the collapse of the Salton Sea ecosystem.

Possible Futures for the Salton Sea

Since at least as far back as the early 1960s, there have been dire predictions that the Salton Sea sport fishery would fail "in the next five to ten years" because of too-high salinities: "but without such measures [an evaporation pond] the Sea would become so salty that the fishery would be seriously damaged within a few years, probably some time between 1970 and 1980" (Pomeroy and Cruse 1965). Such predictions are based on the fact that while water can leave this closed, terminal, below sea level basin by evaporation, salts can only accumulate in the remaining lake water, increasing salinity and concentrating any pollutants. There have also been many predictions as to when the Salton Sea would come into water balance, based on the ~2 m evaporation rate (invariant) and inputs from agricultural waste water. But because agricultural inputs are so variable, dependent as they are on climate, water politics, and export and conservation measures, these predictions of surface elevation and timing have always been futile. So far, none of these predictions has come to pass.

The twin and conflicting problems of stabilizing the elevation of the Salton Sea

while maintaining its salinity at a concentration that will continue to support the sport fishery have often been discussed and studied over the years. The dilemma is real and difficult to solve—allow water elevation to rise to maintain a biologically viable salinity, and shoreline structures and agricultural fields will continue to be drowned; stabilize elevation to protect the shoreline, and salinity will rapidly rise to concentrations lethal to sport fish and then other biota.

Ecologists always have difficulty in predicting future states of ecosystems in response to major or minor changes, human-caused or natural. In one important attempt to assess the effects of a major rise in Salton Sea salinity, Hurlbert's group at San Diego State University published a series of papers on Salton Sea microcosm ecology (González et al. 1998; Hart et al. 1998; Simpson and Hurlbert 1998; Simpson et al. 1998). Microcosms composed of Salton Sea water, shoreline sediment, and biota were set up in 380 liter fiberglass tanks and monitored for 15 mo (1991 to 1992) in San Diego CA. Additional biota from Imperial Valley aquaculture ponds were also inoculated, to simulate possible new biota arriving when Salton Sea salinities become much higher than at that time (43 to 47 g l^{-1}). Microcosm salinities ranged from 30 to 65 g l^{-1}, and were maintained at desired salinities through addition of fresh water. Temperatures were those experienced on a roof in San Diego, a city famous for its salubrious climate which varies little in temperature either diurnally or seasonally; nevertheless microcosm temperatures varied from 6 to 32°C, not much different in extremes from the Salton Sea. Juvenile tilapia (*Oreochromis mossambicus*) were added to some microcosms to simulate effects of fish predation, competition, feeding, excretion, and egestion.

Simpson et al. (1998) pointed out that while many biologists and limnologists believe that physical extremes of salinity, temperature, and oxygen control the distributions of biota in saline lakes, their laboratory microcosm studies demonstrated that biological interactions (competition and predation) are often important mechanisms in structuring saline lake communities. Loss of a dominant predator or competitor, perhaps because of salinity limitations, can lead to major changes in abundance of other species.

Taken as a group, these microcosm studies indicate there will be two critical salinities when the Salton Sea ecosystem will undergo major restructuring (González et al. 1998; Hart et al. 1998; Simpson et al. 1998):

- When the salinity rises high enough ($\sim$60 g l^{-1}) that all the major fish species are eliminated, with a resultant increase in absolute and relative planktonic and benthic invertebrate densities, now released from predation.
- When the salinity rises so much higher ($>>$100 g l^{-1}) that the present major planktonic and benthic invertebrates are eliminated through physiological intolerance. *Artemia franciscana* will likely become the dominant zooplankter and larvae of *Ephydra riparia,* the dominant benthic animals.

These predicted changes are congruent with the distributions of biota in many existing salt lakes. One can look at other terminal saline lakes in closed basins to seek models of what might occur as the Salton Sea becomes increasingly saline; a future Salton Sea is likely to track none of these:

- California's Mono Lake had a salinity of 52 g l^{-1} in 1940, before it was subject to water diversion and desiccation by the Los Angeles Department

of Water and Power. The salinity increased to ~95 g l^{-1} at its elevational low point in 1982, when its elevation had dropped by 19 m. Because of a sweeping 1994 legal decision, the Department of Water and Power must reduce diversions and allow Mono Lake to rise to an elevation where the salinity would drop to ~70 g l^{-1}. Saline and alkaline (*p*H ~10), Mono Lake has not supported fish in historic times. Its macroinvertebrate fauna is dominated by the brine shrimp *Artemia monica* and the brine fly *Ephydra hians* (Winkler 1977; Gaines 1981; Mono Lake Ecosystem Study Committee 1987; Hart 1996). Mono Lake is oligotrophic, fed by low-nutrient precipitation, Sierra Nevada runoff, and groundwater, not by nutrient-rich agricultural waste waters.

- Utah's Great Salt Lake (*p*H 8) has a variable (depending on precipitation) elevation with a salinity of ~130 g l^{-1} (south arm) to ~340 g l^{-1} (north arm) (Hammer 1986). Despite major differences in water chemistry, its biology is generally similar to that of Mono Lake, being dominated by brine shrimp (*Artemia franciscana*) and brine flies (*Ephydra hians* and *E. gracilis*: Herbst 1999); there are no fish (Gaines 1981). The Great Salt Lake is oligotrophic, fed primarily by low-nutrient precipitation and mountain runoff, and only to a small extent by nutrient-rich agricultural waste waters.
- The Dead Sea (Israel and Jordan) has a salinity >350 g l^{-1}, and not only has no fish, but also has no multicellular plants or animals. Its biology is dominated by photosynthetic and nonphotosynthetic prokaryotes, eukaryotic algae and protozoa (Hammer 1986). The Dead Sea is oligotrophic, fed almost exclusively by the increasingly diverted Jordan River, only rarely by low-nutrient precipitation and mountain runoff, and even less by agricultural waste waters; its elevation has been dropping in the past 50 yr at the rate of 0.7 m yr^{-1} (Al-Weshah 2000), and its salinity has risen concomitantly.
- The shriveled Aral Sea (former Soviet Union, now Uzbekistan) is a tragic monument to the worst of Soviet agricultural policies and practices, beginning in the 1920s, aimed at growing cotton in Central Asia. The major rivers feeding the Sea were almost completely diverted for cotton irrigation. Formerly the world's fourth largest lake, the Aral Sea has now lost 80% of its volume and exposed 34.6 million ha of former Sea bed; the shoreline in places has retreated as much as 70 km. The prediction is that the Aral Sea will break into three separate small salt lakes by around 2010. The desiccated Aral Sea has created a number of major problems including air pollution (about five toxic dust storms per year, reaching as far away as Pakistan and Arctic Russia), loss of all 24 native fish species, a destroyed fishing industry, salinized and water-logged soils, and a continuing decline in cotton production. Costly proposals are being made to slow or even stop further degradation, to protect human health, and to maintain at least some wetlands for wildlife, including such expensive projects as importing water 2574 km from the Ob and Irtysh Rivers in Siberia (Micklin 1988; Cagle 1998; Cohen et al. 1999; Stone 1999).

None of these saline lakes serves as a good model for any future Salton Sea. It must be emphasized that the successive desiccations of the many iterations of Lake Cahuilla in the Salton Trough do not offer a good model for what might

happen to a desiccating Salton Sea either. Lake Cahuilla was an oligotrophic freshwater lake, populated by a native freshwater biota derived both from drowned springs and streams and from the Colorado River. It was a flow-through freshwater system with an outlet (often the Río Hardy) to the Gulf of California. By contrast, the Salton Sea is a hypereutrophic hypersaline lake with no outlet other than evaporation, fed only by agricultural wastewater, populated by a species-poor but population-rich quasi-marine biota introduced from all over the world.

In January 2001, the US Supreme Court greatly restricted wetlands protection under the 1972 US Clean Water Act (Solid Waste Agency of Northern Cook County *vs.* Corps of Engineers). The court concluded that the Act covered only those waters that are navigable or connected to a navigable waterway, thus denying federal protection to any landlocked body of water, likely including the Salton Sea, Mono Lake, the Great Salt Lake, vernal pools in California, prairie potholes (vital puddle duck nesting sites), and other terminal lakes in closed basins, no matter how important to resident and migratory wildlife—perhaps 20% of the remaining inland water bodies in the US. The decision overturned the migratory bird rule under which the US Army Corps of Engineers prevented landowners from filling or polluting wetlands (*Los Angeles Times* 10 January 2001).

"Restoration" of the Salton Sea

Since at least the 1960s, proposals to "restore" or "save" the Salton Sea have been put forward. A major set of goals and alternatives was presented in January 2000 by the Salton Sea Authority and US Bureau of Reclamation (2000a see below). All such proposals, including these, suffer from major, perhaps even fatal, defects, including lack of a vision about what state the Salton Sea would be "restored" to (e.g., Friend 1999; Salton Sea Authority and US Bureau of Reclamation 2000a), crucial gaps in scientific knowledge of how the Salton Sea ecosystem works, similarly crucial gaps in knowledge of which problems are most affecting the Salton Sea adversely, and a narrow focus on salinity *per se* rather than on other parameters that may currently be affecting the Salton Sea ecosystem adversely. Research and restoration agendas are driven more by politics and agriculture than by science. Four decades of proposals have foundered on their great cost and lack of funding, even though economic analyses of maintaining an ecologically viable Salton Sea show that there will be major net benefits to communities of the Salton Trough. Bazdarich (1998a,b), deliberately ignoring the economic benefits of the sport fishery, hunting, and birding, calculated a benefit of nearly $5 billion for "improving" Salton Sea conditions to a "state conducive to widespread economic development," and another $3.3 to 5.7 billion in benefits from "preventing further pollution," as he seemed to think the Sea is polluted. (It isn't: see above.)

Components of these "restoration" proposals fall into several general categories:

Diked evaporation ponds within the Salton Sea (salt harvesting).—The most popular proposal is to remove salts from the Salton Sea by way of a diked evaporation pond built within the Salton Sea, occupying as much as one-half the present area of the Sea. This impoundment would evaporate Salton Sea water and

collect salts, preventing them, plus any contaminants, from returning to the Sea. Any diked impoundment would reduce the area and volume of the Salton Sea. Since a pond would displace a portion of the Sea, the elevation of the remainder of the Sea could be maintained closer to target elevation (Salton Sea Authority and US Bureau of Reclamation 2000a). Three of the five Phase 1 alternatives presented by the Salton Sea Authority and US Bureau of Reclamation (2000a) involved evaporation ponds, differing in their locations and numbers, and whether they also involved the Enhanced Evaporation System approach (see below). Proposed sizes of impoundments have ranged from 8% to 50% of the surface area of the Sea, and proposed locations have included all areas of the Sea. Some proposals involve building dikes as much as 20 meters or more high (White and Hart 1996). Construction of dikes would greatly increase suspended sediments in the Sea, along with associated Se, trace elements, and H_2S, all probably adversely affecting the biota and perhaps public health (Salton Sea Authority and US Bureau of Reclamation 2000a).

Most proposals for diked evaporation ponds place them in the gently-sloping shallow southern or northern parts of the Salton Sea, in the most productive parts of the Salton Sea in terms of benthos, sport fishery, and water-related birds. The Salton Sea Authority and US Bureau of Reclamation (2000a) did not discuss these serious problems: "[T]he shallow water habitat that currently exists and is utilized by a number of species will change." This is a totally inadequate analysis.

Large diked ponds in the Salton Sea could hinder water circulation and current velocities in the remaining Sea; interfere with water inflow from the rivers; cause scour or sediment deposition; change transport routes of nutrients, trace elements, and biota; and change horizontal and vertical temperature, oxygen, and salinity gradients. Models to predict such changes (Cook and Orlob 1997; Cook et al. 2000) are summarized by the Salton Sea Authority and US Bureau of Reclamation (2000a). In these models, the fundamental counterclockwise circulation in the southern basin is not altered, but there are sometimes important local changes in all these parameters, including eddies at the mouths of the New and Alamo Rivers.

How to dispose of hypersaline wastes collected in evaporation ponds is a major problem. Evaporation ponds would quickly become uninhabitable for any biota but prokaryotes. The Salton Sea Authority and US Bureau of Reclamation (2000a) estimated that evaporation ponds would reach 200 to 244 g l^{-1} in just 7 yr, at which point salts would begin to precipitate out. At best, these evaporation ponds might simulate natural saline playa lakes. The 1974 Feasibility Report (US Department of the Interior and The Resources Agency of California 1974a,b), recommended a 154 km^2 impoundment and suggested pumping evaporation pond brines outside the Salton Trough to Palen Dry Lake basin to the northeast, while pointing out that this approach would meet with public opposition.

Evaporation ponds would concentrate substances, such as Se, trace elements, and pesticides, that are known to affect bird reproduction adversely elsewhere. This did in fact happen at evaporation ponds at Kesterson, leading to abandonment and capping of the ponds. Any Salton Sea evaporation pond would have to be created in such a way that birds could not use it for feeding, nesting, or resting, to avoid developmental anomalies and reproductive failure. Ducks and other waterfowl become covered with crystalline salt and die from sodium toxicity when visiting saline playa lakes in New Mexico (Meteyer et al. 1997). Evaporation

ponds in the Salton Trough might well cause the same problems even if potential pollutants did not reach hazardous concentrations.

If no water diversions are made, the Salton Sea Authority and US Bureau of Reclamation (2000a) estimated from models that the remainder of the Salton Sea would continue to rise in elevation, overtopping dikes in around 25 years. On the other hand, if the Sea were allowed to drop in volume and elevation, existing inflows from agricultural wastes would lower the salinity, according to supporters of this approach. But allowing Sea elevation to drop would expose many km^2 of salt and mud flats as a "bathtub ring" around the Sea. There would be downcutting of unlined rivers, canals, drains, and washes in both the Imperial and Coachella Valleys, dewatering wetlands and riparian areas. Between the exposed salt flats and the stark dikes in the Salton Sea, any evaporation pond is likely to have a significantly adverse visual impact, as would the Displacement, Pupfish Pond, and North Wetland Habitat dikes (see below). The Salton Sea Authority and US Bureau of Reclamation (2000a) proposed to paint the dikes beige to mitigate these adverse visual effects.

Discussions of the diked evaporation pond approach have not indicated whether it could be combined in any way with the diked solar pond proposal for electricity generation (WESTEC Services Inc. 1981).

Any diked evaporation pond would be susceptible to earthquake damage, breaching dikes and releasing hypersaline water into the remaining Salton Sea. It is hard to imagine any dike withstanding lateral or vertical offsets up to 5 to 6 meters, as occurred during the 1941 Imperial and 1892 Laguna Salada earthquakes. The Salton Sea Authority and US Bureau of Reclamation (2000a) discussed the possibility of earthquake-breached dikes, but did not adequately address how to prevent or alleviate the nearly certain adverse consequences of brine spills through breached dikes. In addition, earthquakes might generate seiches in the ponds, causing water to overtop the dikes even if the dikes themselves did not fail.

The 1974 Feasibility Report's overall conclusion was that only a diked evaporation pond approach was remotely feasible for stabilizing the Salton Sea at 35 g l^{-1} while also stabilizing its elevation (US Department of the Interior and The Resources Agency of California 1974a,b).

Estimates of \$300–500 million have recently been made to "preserve" the Salton Sea and its sport fishery using the diked evaporation pond approach, with \$1.25 to 2.5 million needed for yearly maintenance. Cohen et al. (1999) estimated that the total cost of the diked evaporation pond approach might be as much as \$1 to 2 billion if protective measures against earthquake damage were included.

Enhanced evaporation system (salt harvesting).—This proposal, based on showerline technology which has been used in Israel, involves pumping Salton Sea water out of the Sea to the adjacent desert, where the water would be misted and evaporated from high (~98 m) towers. About 150,000 acre-feet yr^{-1} would be removed from the Sea. Ideally, salts would precipitate in the air and be collected in catch basins below the towers and kept from returning to the Salton Sea. Catch basins would have to be large enough to collect wind-blown water and salts, an adverse effect which the Salton Sea Authority and US Bureau of Reclamation (2000a) discussed but did not propose adequate mitigations for. Its major

mitigation would be to shut down the showerline when winds exceeded 22 to 26 km hr^{-1}. Furthermore, it is very likely that not all the water would be evaporated in the air, so that the catch basins would have to be constructed to catch and hold hypersaline water as well as salts. These basins must be lined to prevent brines from contaminating groundwater, canals, drains, or the Salton Sea. Problems with birds would have to be averted (see above). These hypersaline waters and desiccated salts would have to be disposed of (see above). It is estimated that around 66 km^2 of desert land would be needed, proposed for either the Navy's closed Salton Sea Test Base or east and north of Bombay Beach. The Salton Sea Authority and US Bureau of Reclamation (2000a) stated that the Bat Caves Buttes northeast of Bombay Beach and the graceful crescent-shaped sand dunes (barkhans) just southwest of the Naval Test Base are both "expected" to be protected from construction and operation of the Enhanced Evaporation System. A showerline array in either location would have major visual impacts, due to the height of the towers and the gentle topography. The Salton Sea Authority and US Bureau of Reclamation (2000a) proposed setting up radar surveillance to detect nocturnal bird migration and to shut down the showerlines to prevent mass mortality. Use of the Salton Sea Test Base site may increase the salinity of San Felipe Creek water through groundwater seepage; the Salton Sea Authority and US Bureau of Reclamation (2000a) proposed lining the catchment ponds to avert this problem.

Four of the five alternatives proposed by the Salton Sea Authority and US Bureau of Reclamation (2000a) involve the Enhanced Evaporation System, differing in the location of the system (Salton Sea Test Base or Bombay Beach) and whether it is combined with evaporation ponds. The Salton Sea Authority and US Bureau of Reclamation (2000a) concluded that a combined evaporation pond-Enhanced Evaporation System approach offers the greatest flexibility in managing both salinity and elevation.

A demonstration of this system was conducted in early 2000 on a very small scale, using a Turbo Mist machine towed by a tractor. One Turbo Mist can remove 22 metric tons salt per day, but to maintain the current salinity, 1.36 million tons of salt would have to be removed from the Sea each year (*Los Angeles Times* 2 March 2000). This showerline approach has been vigorously opposed by residents and others, and is no longer used in Israel because of problems with wind-driven saline mists on agricultural fields (San Jose CA *Mercury News* 15 February 2000; *San Diego Tribune* 6 August 2000).

Pump-out.—Over the years, proposals have been made to pump hypersaline Salton Sea water out of the Salton Trough. Most proposals involve an exchange with lower-salinity water from another source, and so are discussed below. Pump-out options, absent any pump-in of water, can lead only to a decline in elevation of the Salton Sea. Exporting Salton Sea water to the ocean, no matter where, may lead to serious biological impacts, such as introduction to the ocean of alien species (tilapia is the one most written about) that may adversely affect coastal oceanic organisms and ecosystems. Export of hypersaline Salton Sea water to the former Colorado Delta may further degrade this already profoundly degraded wetland system, a United Nations International Biosphere Reserve. Mellink and Ferreira-Bartrina (2000) argue that the delta does not merit Biosphere Reserve status, as its biology is so very altered. The two Gulf alternative destinations

(Salton Sea Authority and US Bureau of Reclamation 2000a) are the Golfo de Santa Clara just downstream from the Ciénega de Santa Clara, and near San Felipe on the west side well south of the northern shoreline. The northern Gulf of California does not mix rapidly with the rest of the Gulf (Salton Sea Authority and US Bureau of Reclamation 2000a). Pumping to the Pacific Ocean (either Gulf of California or near San Diego) would require major energy expenditure, as Salton Sea water would have to be raised ~74 m just to reach ocean sea level, plus whatever pumping is needed to get over or through intervening mountains. Pumping to the Gulf would require the cooperation of México. The large aqueducts needed (diameter around 2.5 to 3 m) could be broken by earthquake ruptures, releasing Salton Sea water onto sensitive lands or waters.

Export to Palen Dry Lake basin northeast of the Salton Trough (lowest elevation 140 m above ocean sea level, around 214 m above current Salton Sea elevation) may lead to transmission of pathogens such as avian cholera and avian botulism, plus high concentrations of toxic substances, affecting bird reproduction just as at Kesterson. About 250,000 acre-feet yr^{-1} would be exported. At its maximum, the new Palen Lake would be around 328 km^2 in area, nearly 50% the size of the present Salton Sea. Because of its elevation, significant energy would be required to pump Salton Sea water to Palen Dry Lake, and a dam around 5 to 7 m high would have to be built to prevent water from spilling over into adjacent desert basins. Earthquakes may cause dam failure or break aqueducts. In effect, pumping Salton Sea water to Palen Dry Lake would create a second, smaller Salton Sea, complete with all the problems that the present Salton Sea supposedly has.

Some have proposed pumping Salton Sea water into the Laguna Salada in México, an alternative that would involve much less energy, but which would create not only the same problems as pumping to Palen Dry Lake but would create the risk of overflowing into the Gulf of California since the Laguna Salada is supposedly occasionally filled by extremely high tides in the Gulf (Residencia General de Cerro Prieto 1998); it already receives Mexican irrigation wastewater. México would have to agree.

Screening any pipeline intake from the Salton Sea is proposed by Salton Sea Authority and US Bureau of Reclamation (2000a) to guard against introductions into receiving waters. Since this approach is rarely adequate elsewhere (small fish and other biota readily get through most aqueduct screens), it is unlikely to work any better here.

Several scenarios would result in Sea elevation declines of as much as 3 to 5 meters, which might re-create a land connection to Mullet Island, which has been an island for around 50 years and which is a major nesting site for colonial waterbirds such as California brown pelicans and double-crested cormorants. A land connection would permit access by such land-based predators as coyotes, kit foxes, striped skunks, raccoons, and feral dogs and cats. The Salton Sea Authority and US Bureau of Reclamation (2000a) suggested surrounding Mullet Island with a dike, preventing land predator access. But a dike would not prevent access by land predators; surely the Authority meant a moat.

Aside from the concomitant increased salinity, any elevation drop will expose a "bathtub ring" of salt flats around the entire perimeter of the Sea, widest at the shallow southern and northern ends, leading to potentially serious air pollution

(dust, other particulates, pesticides, Se, and trace metals). An elevation drop of 3 m would expose ~9142 ha, all susceptible to wind erosion and wind-mobilizing of sediments of potential harm to human health and crops downwind in the Imperial Valley. Federal and state standards for particulate air pollution are already frequently exceeded in the Salton Trough (Salton Sea Authority and US Bureau of Reclamation 2000a). An increase of 10 $\mu g\ m^{-3}$ in daily coarse particulates (>10 μm diameter: PM10) in the Coachella Valley was associated with an increase of around 1% in human mortality (Ostro et al. 1999).

Particulate air pollution became a major problem afflicting the Owens Valley east of the Sierra Nevada after the Los Angeles Department of Water and Power dewatered Owens Lake in the early 20th century. The Department of Water and Power has been legally required by the Clean Air Act, US Environmental Protection Agency, and Great Basin Unified Air Pollution Control District to alleviate particulate air pollution in the Owens Valley (273,000 metric tons per year: *Los Angeles Times* 18 August 1999; Cohen et al. 1999). The Department of Water and Power must also assure that the Mono Lake basin to the north meets particulate air quality criteria, in this case by allowing the lake elevation to rise through reduced water diversions to a level that submerges major alkali flats (Hart 1996). Mitigation measures for both lakes will be expensive ($100 million for Owens Lake alone) and will involve use of considerable water (up to 40,000 acre-feet yr^{-1} to rewater Owens Lake) that would otherwise go to Los Angeles, costing Los Angeles additional hundreds of millions of dollars in both lost water and hydroelectric energy (*Los Angeles Times* 18 August 1999).

The Salton Sea Authority and US Bureau of Reclamation (2000a) regarded the potential for increased problems from degraded air quality and human health by wind-blown exposed sediments and precipitated salt deposits to be "less than significant," due to rapid revegetation of these exposed lands, as happened between 1907 and 1925, but pointed out that Clean Air Act criteria must be conformed to and permits must be obtained from both the Imperial County Air Pollution Control District and South Coast Air Quality Management District.

Pump-in.—Under most scenarios (evaporation ponds, Enhanced Evaporation System, water conservation, water transfers), the elevation of the Salton Sea will decline over the next several decades, declining below target elevations. Simulations show that with reduced inflows it will be impossible to control both elevation and salinity without a new source of lower-salinity water (Salton Sea Authority and US Bureau of Reclamation 2000a).

Since the Salton Sea, at ~43 to 47 g l^{-1}, is only ~23% to 34% more saline than the ocean (35 g l^{-1}), pumping in ocean seawater would dilute the Salton Sea only slowly. The major way for any "harvesting salt" project to be successful would be to increase input of fresher water into the remainder of the Salton Sea, either from the Colorado River or from other sources.

The Colorado River is famously over-allocated (Weatherford and Brown 1986a; Reisner 1993; deBuys 1999), and is not a viable source for additional water to assist the Salton Sea. General Manager Mulroy of the Southern Nevada Water Authority is paraphrased as saying, "any attempt to use Colorado River water to save the troubled Salton Sea will kill any chances for consensus" of the seven states of the Colorado River Users Association (*Los Angeles Times* 18 December

1999). Salton Sea Authority Director Kirk announced in August 2000 that the Authority had dropped any proposals to use additional Colorado River water to dilute the Salton Sea, "in response to political considerations" (*Los Angeles Times* 2 August 2000). What that means is strong opposition from California and Arizona agricultural interests who want all Colorado River water for themselves and environmentalists who do not want any further degradation of the Colorado River Delta in México (San Francisco *Chronicle* 6 August 2000). Director Kirk was quoted as being optimistic about finding other sources of water; however, alternative water sources have not been identified, let alone developed.

One alternative is to use treated domestic waste water from the secondary Point Loma Wastewater Treatment Plant in San Diego, with a salinity of around 1.75 g l^{-1}, and perhaps a capacity as high as 266,000 acre-feet yr^{-1}. An 85 km pipeline, around 3 m in diameter, would be used to reach the mountains of eastern San Diego County, where the water would enter a 34 km tunnel under the mountains, followed by a 53 km gravity pipeline to the Salton Sea. Further wastewater treatment would be required before this water could be discharged into the Sea. A variation of this approach would be to use municipal wastewater generated by San Bernardino or other San Bernardino or Riverside County cities. The Salton Sea Authority and US Bureau of Reclamation (2000a) rejected both these wastewater alternatives.

The as-yet unbuilt Central Arizona Salinity Interceptor would take ~304,800 acre-feet yr^{-1} of municipal, industrial, and irrigation wastewater (around 4.4 to 5 g l^{-1}, seven times lower than the Sea's target salinity) from the Phoenix and Tucson areas by gravity to Yuma (Salton Sea Authority and US Bureau of Reclamation 2000a). It is still unknown how concentrated Central Arizona Salinity Interceptor water would be in potentially toxic substances such as pesticides, Se, and trace metals, as well as nutrient concentrations. Since the Interceptor and associated water treatment plant are now only being "considered" by Phoenix and Tucson, the ability to use Interceptor water to assist the Salton Sea would at best be 25 years in the future. The water would arrive by canal at Yuma, enter a new, lined canal constructed mostly parallel to the All-American Canal, and then use the Alamo River for conveyance to the Salton Sea, taking advantage of the wide upper river bed created by the 1905 to 1907 flood. The many critics say, among other things, that this proposal is "designed to feed the Bureau of Reclamation's appetite for large-scale engineering projects." Michael Cohen of the Pacific Institute was quoted, "The Bureau knows only how to build monuments to human engineering, not how to sustain an ecosystem" (San Jose CA *Mercury News* 15 February 2000).

deBuys (1999), based on conversations with longtime director of the Imperial Irrigation District Cox, proposed a novel low-salinity water source for the Salton Sea. Pointing out that now around one third of the water used in irrigation in the Imperial Valley drains to the Salton Sea, Cox and deBuys suggested that one fourth of any "excess" Colorado River water exported from the Salton Trough be retained and run into the Salton Sea, just as it is now. Thus, if the San Diego County Water District were to obtain rights to 200,000 acre-feet yr^{-1}, it would actually receive only 150,000 acre-feet, while 50,000 acre-feet would be directed to the Salton Sea. This proposal seems not to have yet been vetted in public, and would surely be opposed by any recipient water agency.

Pump-in–pump-out.—Merely pumping low salinity water into or pumping hypersaline water out of the Salton Sea is unlikely to be adequate in maintaining both elevation and a viable ecosystem. Rather, most proposals combine Pump-In and Pump-Out—an exchange of high for lower salinity water, for example, exchanging hypersaline Salton Sea water with ocean seawater from the Gulf of California or from the Pacific Ocean near San Diego. This approach would require the active participation of México, huge volumes of water, immense aqueducts, a tremendous amount of energy to pump water both directions, and the severe risk of destroying the Salton Sea ecosystem and sport fishery through contamination by Gulf or ocean biota. The Salton Sea Authority and US Bureau of Reclamation (2000a) stated that to exchange sufficient water to bring the Sea's salinity back down to 40 g l^{-1} would require moving 1.1 million acre-feet yr^{-1} of water each direction, and much more should water conservation in the Imperial Valley reduce the Sea's present 1.3 million acre-feet yr^{-1} inflow.

The 1974 Feasibility Report (US Department of the Interior and The Resources Agency of California 1974a,b) discussed three approaches to pumping hypersaline Salton Sea water out of the Trough combined with importation of ocean seawater to stabilize elevation and salinity, concluding, "This plan was found to be infeasible," even without addressing any adverse biological impacts to the Salton Sea of ocean water exchange.

One variant of Pump-In—Pump-Out is to dredge a deep water ocean seaport at Mexicali ("Port Mexicali") as part of the water exchange system. Then build a pipeline from the Gulf of California to pump ocean seawater into the Laguna Salada, from which water would flow by gravity to the Salton Sea, generating hydroelectricity. Using this power (and more), water would then be pumped from the Salton Sea uphill to Mexicali; an ocean sea level ship canal would lead from "Port Mexicali" back to the Gulf. A variation on this proposal puts the seaport in the Laguna Salada (White and Hart 1996). Quite aside from all the other probable problems (see above), how would the "Port Mexicali" proposal function with the 10–13 meter tides in the northern Gulf, not mentioned by the proposers?

Exchanging water between the Salton Sea and the Gulf of California is an approach that has generated a number of impossible, even ludicrous, proposals. As one example, according to the Palm Springs *Desert Sun* (10 January 2000), Metcalf and Eddy, an engineering firm in Wakefield MA, proposed a $3.3 billion project to build two parallel ocean sea level canals between Sea and Gulf to within 1.6 km of the Sea, ending in "a system of locks" to "drop the water—and pleasure boats and small barges—down to the Salton Sea, a [70 meter] drop." If these canals were truly at ocean sea level in the Imperial Valley, they would have to be supported by something like a trestle, ultimately nearly 70 meters high near the shoreline and strong enough to support both water and barge traffic. Metcalf and Eddy apparently ignored the problem of those 10–13 meter tides in the Gulf and presumptive catastrophic collapse of the strange but productive Salton Sea ecosystem from biotic contamination from the Gulf. The Pacific Institute's Michael Cohen was quoted, "I think that, once we stopped laughing, we'd oppose it" (*Desert Sun* 10 January 2000).

The Gulf alternative (including the "Port Mexicali" version) would initially cost more than the diked evaporation pond proposal, but supposedly would have greater long-term benefits. But unless difficult and expensive measures are taken

to prevent colonization (contamination) of the unusual but highly productive Salton Sea ecosystem with Gulf biota—unlikely to be successful—major biological problems will occur, surely including the rapid collapse of the present sport fishery through inadvertent introductions of new species of marine fish and other marine biota. Mere screens over the intakes will not suffice.

Desalinate salton sea water (salt harvesting).—At first glance, removing salt from Salton Sea water and returning the water to the Sea as fresh water seems a promising alternative. The 1974 Feasibility Report (US Department of the Interior and The Resources Agency of California 1974a) discussed utilization of a desalinization plant and concluded that it was "prohibitively costly." In 1974 they could not yet discuss using the federal desalinization plant south of Yuma (Fig. 5), finished in 1992, required as part of a 1973 compact between the US and México (Minute 242 of the International Boundary and Water Commission). After lying idle for several years, the Yuma Desalting Plant has now been put into operation, with no consideration of the effects of its effluents on downstream ecology in the Colorado Delta, particularly the Ciénega de Santa Clara (Glenn et al. 1992; Mellink and Ferreira-Bartrina 2000). An official of the Colorado River Commission was quoted, "We could have bought up the Wellton-Mohawk Project [in Arizona] and retired the whole thing for a lot less than [the desalinization plant] is going to cost, but politically, of course, it is not feasible" (Sheridan 1981). This proposal would be by far the most expensive, both in terms of construction of the desalinization plants and the energy to remove salts from the water.

The "do nothing" alternative.—Of course, one could do nothing at all, letting the future of the Salton Sea (volume, elevation, salinity, biota, ecology, sport fishery, birds) continue to be at the mercy of the policies of the irrigation districts. There is no question that waste agricultural inflows (now around 1.3 million acre-feet yr^{-1}) will decline significantly, perhaps to as low as around 800,000 acre-feet yr^{-1}, both because of enforced water conservation and because of marketing water outside the basin. With a drop in elevation, there will be a rapid rise in the salinity of the Sea, and consequent loss of the sport fishery and then other current biota.

See Cohen et al. (1999) for a description of one scenario to turn the Salton Sea into an *Artemia-Ephydra,* fishless salt lake. Should the Sea become fishless, the sport fishery will of course have collapsed, and the Sea would be of only limited value to the present avifauna of the Salton Trough.

While models and simulations have been developed and used for small subsets of these approaches (Salton Sea Authority and US Bureau of Reclamation 2000a) no comprehensive model has been developed or used to cover all the major water issues in the Colorado River basin as a whole. Such models exist (T. Hand pers. comm.) and are being used for watershed analyses both in this country (Chesapeake Bay, Mississippi River) and abroad. Hand has developed a model for the Mekong River system in Asia, which involves seven countries, major dams, agricultural and other water diversions, and Tonlé Sap (a seasonally variable salt lake in Cambodia) with conflicting demands for fish production and agriculture not unlike the Salton Sea area. Without such comprehensive models, planning for the Colorado River and the Salton Sea can only be deficient.

California's Water Quality Control Board made the first study of problems facing the Salton Sea and preliminary plans to control salinity rise (Pomeroy and Cruse 1965). The 1965 Pomeroy Report startled many by predicting that without salinity control measures, the Salton Sea's popular sport fishery would soon collapse, "probably some time between 1970 and 1980." The 1965 Pomeroy Report urged early action and recommended further study (Pomeroy and Cruse 1965; US Department of the Interior and The Resources Agency of California 1969, 1974a,b).

As a direct result of Pomeroy Report recommendations, a late 1960s task force made the first diked evaporation pond proposal (Calhoun 1969; US Department of the Interior and The Resources Agency of California 1969). In 1971, a report was issued by The Aerospace Corporation on behalf of the US Air Force, presenting engineering studies of a wide range of possible solutions; this report recommended further study. The 1969 Reconnaissance Study was followed up in 1974 by a more detailed Feasibility Report and Environmental Impact Report by the same agencies (US Department of the Interior and The Resources Agency of California 1974a,b). Both reports concluded that a diked evaporation pond was the best way to stabilize both salinity (at concentrations to maintain the sport fishery) and elevation. The calculated benefit-cost ratio was 4:1, very favorable. In neither case was any action taken.

There was a flurry of political activity about the Salton Sea in the early 1970s because then-Rep. Veysey (R-Palm Springs CA) was concerned. A $200,000 study of the salinity problem and possible solutions was authorized by Congress (*Los Angeles Times* 29 April 1973). But Rep. Veysey was gerrymandered out of the Coachella Valley by redistricting and then lost his next election bid to Congress. The 1970 study resulted in no action, despite the fact that it made a strong case for the biological viability of the Salton Sea and described relatively inexpensive solutions for maintaining the sport fishery.

A Salton Sea Task Force was formed in 1988, composed of representatives from federal, state, county, and local agencies, all appointed by the California Resources Agency. The Task Force concluded that the diked evaporation pond approach was the best. The Task Force was dissolved in 1993 in favor of the Salton Sea Authority, formed under Joint Powers Authority by the California legislature (Cohen et al. 1999). The Salton Sea Authority has the power to tax and spend funds and to enter into binding contracts. Its board includes members from the Coachella Valley Water District, Imperial Water District, and Riverside and Imperial Counties. No scientists or others knowledgeable about the ecology of the Salton Sea are on the Board, although there is a Science Subcommittee. No representatives from México are formally involved. The legal mandate for the Authority focuses on continued agriculture in the region and recreational and economic development, not ecological restoration, thus excluding a significant public interest and many possible alternatives (Cohen et al. 1999).

From its beginning, the Salton Sea Authority discussed, evaluated, and rejected most of 68 proposals to "restore" the Salton Sea, eventually settling on several "salt harvesting" alternatives. Screening criteria included: (1) stabilize the Sea's elevation at around -76.1 m below ocean sea level; (2) reduce the Sea's salinity to 40 g l^{-1}; and (3) use only proven technology (Cohen et al. 1999). These narrow criteria excluded wildlife and ecosystem values. Among the rejected proposals

were those which would reduce nutrient loading and alleviate other potential water quality problems. Even though there have already been demonstration projects to reduce Se input and to improve agricultural drainwater quality prior to discharge to the Sea, these were not incorporated into Phase 1 of the Restoration Plan (Cohen et al. 1999; Salton Sea Authority and US Bureau of Reclamation 2000a). The Authority and its discussions were not much noticed until the late 1990s.

Beginning in 1997 there was again some stirring of political interest at both state and national levels to protect the Salton Sea sport fishery by finding some feasible way to control both rising salinity and elevation. The 1996 bird and 1999 fish die-offs were headline news in major southern California newspapers and on television. In August 1997 a multi-agency workshop was held in Palm Springs to discuss ways to develop and evaluate programs to address problems with elevation, water quality, and salinity, with the existing Salton Sea Authority as lead agency.

Then-Rep. Sonny Bono (R-Palm Springs CA) was taking a leadership role on this issue in Congress, the major potential source of funding. According to deBuys (1999), Rep. Bono wanted the Sea to become a "premier destination resort and residence opportunity" with floating island marinas, intense shoreline development, major economic opportunities for residents and Indian tribes, and a first-class resort.

Remarkably, Rep. Bono's death in a skiing accident in January 1998 changed the political dynamic in Congress. A week after Rep. Bono's funeral, then-House Speaker Gingrich (R-GA) toured the Sea and announced a multiyear plan to reduce the Sea's salinity and the amount of inflowing pollutants. "Our goals should be to have the Salton Sea have the most fish, the most birds, and the most viable economy it can possibly have," said Gingrich in announcing the Salton Sea-Sonny Bono Restoration Project. His three-part plan included: (1) using money already allocated to build a New River treatment facility in cooperation with state and federal agencies; (2) developing a complex of marshes along the New River to filter and clean its water; and (3) committing Congress to decide which of two methods to use first to stabilize and then reduce the Sea's salinity, either (3a) the diked evaporation pond approach, or (3b) making a direct connection to the Gulf of California to pump Salton Sea water into the Gulf in exchange for normal salinity Gulf water to refill the Sea. All these proposals are described above. Gingrich said that the economic impact of a "restored" Salton Sea would be from $6 to 10 billion as a sports fishery and recreation area, with an annual benefit of $270 to 360 million, so that the cost of saving and maintaining the Sea would be small compared to the benefits.

In October 1998 Congress passed Public Law 105–372, the Salton Sea Reclamation Act but appropriated only $5 million for yet another study of the Salton Sea ecosystem, geochemistry, problems, and possible solutions, due on 1 January 2000; Congress appropriated another $13.1 million to the Environmental Protection Agency to assist the Authority (deBuys 1999; Kaiser 1999; Salton Sea Authority and US Bureau of Reclamation 2000a). The act named California's Salton Sea Authority and the US Bureau of Reclamation as the lead agencies responsible for overseeing the Salton Sea restoration project. In the discussion to follow, they will be referred to as the Authority. This act also renamed the federal wildlife refuge after Rep. Bono.

The Authority enumerated five long-term goals for the Salton Sea Restoration Project:

1. Maintain the Sea as a repository for agricultural drainage. The Authority's Environmental Impact Report (Salton Sea Authority and US Bureau of Reclamation 2000a) pointed out that the Salton Sea would not exist in the absence of agricultural drainage from the Coachella and Imperial Valleys and Valle de Mexicali.
2. Provide a safe, productive environment at the Sea for resident and migratory birds and endangered species.
3. Restore recreational uses at the Sea.
4. Maintain a viable sport fishery at the Sea.
5. Enhance the Sea to provide economic development opportunities.

These official goals significantly constrain possibilities for maintaining the unique ecosystem of the Salton Sea, since maintaining agricultural drainage is the most important goal. While preserving the ecological integrity of the Salton Sea may be implicit in Goals 2 and 4, it is not explicit. Goals 3 and 5 have nothing directly to do with the ecology of the Salton Sea. As a consequence of these narrow goals, proposals by the Authority do not address some of the most important issues concerning the Salton Sea. A summary of the Authority's plan is given by Cohn (2000), but with little critique. A much more balanced and analytical critique of the Authority's plan was published by Nijhuis in the Paonia CO *High Country News* (19 June 2000, ⟨www.hcn.org/⟩).

In January 2000, the Authority unveiled its proposal for Phase 1 of the Salton Sea Restoration Project, presenting five alternatives combining just two methods to control Salton Sea salinity and elevation—the diked evaporation ponds and enhanced evaporative systems described above (Salton Sea Authority and US Bureau of Reclamation 2000a). Costs were projected to be great. Using "excess" Colorado River flood waters alone would cost $10 million. Building diked evaporation ponds would cost $400–465 million. The showerline approach would cost $300–425 million (Cohn 2000). In a 28-page analysis of the Authority's Draft Environmental Impact Report, the US Environmental Protection Agency was harsh: the Draft was "inadequate" in a number of ways. The EPA believed "there is no assurance the project will meet its objectives, even after a significant expenditure of resources." The Authority's report failed to detail water-quality standards, did not evaluate how reaching certain goals would adversely affect other restoration plans, and handled data on inflows inconsistently. The Environmental Protection Agency wanted a much more broadly defined project to assure sustaining a viable ecosystem in the Sea (Palm Springs *Desert Sun* 17 May 2000).

Key findings of the Science Subcommittee, most "unexpected" (why?) were (Salton Sea Authority and US Bureau of Reclamation 2000a):

1. The Salton Sea is alive and vibrant in terms of biological complexity rather than nearly dead.
2. Fish populations, thought to be seriously depressed, are actually abundant; in fact, the Salton Sea may be the most productive fishery in the world.
3. Pesticides, presumed to be a major problem, are not; most pesticide con-

centrations in the sediments and waters of the Sea were found to be at or below detection concentrations of the analytical methods used.
4. Though algal toxins have long been thought to be a major cause of fish and bird mortality at the Sea, investigation failed to reveal any evidence of toxins causing either fish or bird kills.

The Authority (Salton Sea Authority and US Bureau of Reclamation 2000a) proposed a set of six "Common Actions" which could be conducted with any of its five alternatives:

1. Harvest "excess" tilapia to reduce phosphorous concentrations and thus reduce eutrophication. As discussed above, there is no valid evidence that such an approach would either work or be beneficial; the proposal is based on unsupported assumptions and inadequate scientific information.
2. Improve recreational facilities by improving boat access.
3. Clean up the shoreline and the Sea surface of dying and dead fish, particularly from locations accessible to the recreational public. The fish would be incinerated.
4. Initiate an Integrated Wildlife Disease Program to minimize losses from fish and avian pathogens through early detection, diagnosis, and appropriate action. The proposed program would be operated by the National Wildlife Health Center of the US Geological Survey, US Fish and Wildlife Service, Salton Sea Authority, and California Department of Fish and Game.
5. Initiate a Long-Term Management Strategy, including long-term operation and maintenance, scientific investigations of the ecology of the Salton Sea ecosystem, and long-term monitoring.
6. Initiate a Strategic Science Plan, a comprehensive life-of-the-project effort of restoration managers to prepare solutions for future changes, based on on-site ecological studies, modeling, and simulations (see Appendix B in Salton Sea Authority and US Bureau of Reclamation 2000a).

In addition the Authority (Salton Sea Authority and US Bureau of Reclamation 2000a) proposed several additional features which would "enhance" any of the five alternatives:

1. Construct a Pupfish Pond, around one meter deep. This pond was proposed for the shoreline along the southwestern Salton Sea, inshore from the southeastern evaporation pond, to permit in-Sea movement of desert pupfish between San Felipe creek and drains from the Imperial Valley. The Pupfish Pond would contain snag habitat for colonial-nesting tree birds such as cormorants, herons, and egrets, though there are few snags there now. Water would be pumped into the Pupfish Pond from the New River. It was not made clear by the Salton Sea Authority and US Bureau of Reclamation (2000a) why the proposed Pupfish Pond is needed, or needs to have a lower salinity than the present or future Salton Sea, since desert pupfish are strongly euryhaline. Desert pupfish are endangered not because of increasing salinity, but because of competition and predation by such introduced animals as tilapia, sailfin mollies, mosquitofish, and bullfrogs. To enhance desert pupfish populations, control and removal of these aliens will be required. Dunham and Minckley (1998) wrote, "The fish needs little more than water

to survive as long as non-native species are excluded." The Authority (Salton Sea Authority and US Bureau of Reclamation 2000a) was not concerned about alien animals and their effects on desert pupfish. The Authority lists a number of ecological drawbacks—some of them severe—to the Pupfish Pond, but does not discuss any mitigations.

2. Develop a North Wetland Habitat, around one meter deep. Justification, design, and concerns for this managed North Wetland Habitat are about the same as for the Pupfish Pond, though the North Wetland Habitat would not be managed specifically for desert pupfish, and water conditions might differ considerably from those in the Pupfish Pond, as water quality would be dominated by inflow from the Whitewater River. The North Wetland Habitat would protect snags for cormorant and heron nesting and maintain several islets to be used by ground nesting colonial waterbirds such as terns and skimmers. The Authority (Salton Sea Authority and US Bureau of Reclamation 2000a) listed a few ecological drawbacks to a managed, diked North Wetland Habitat, but did not address any mitigations. The Authority wrote that the North Wetland Habitat should be used for trials of new technology.
3. Construct a Displacement Dike between the mouths of the New and Alamo Rivers, seawards of the Sonny Bono National Wildlife Refuge to reduce area, volume, and salinity while maintaining the elevation of the Salton Sea (Salton Sea Authority and US Bureau of Reclamation 2000a). Simulations showed that the Displacement Dike would change circulation in the southern Sea basin, causing eddies at the mouths of the New and Alamo Rivers. Salinity would be lower at the mouths of the two rivers than in the Sea itself, which might have effects on the distribution, abundance, and diversity of the biota. When there is standing water within the Displacement Dike, it is likely to be of poor quality. Being adjacent to the federal wildlife refuge, any water there will attract birds, which are unlikely to thrive in it. The Salton Sea Authority and US Bureau of Reclamation (2000a) did not address these issues at all.
4. Augment present inflows to the Salton Sea by using a portion of the total "excess" flood flows available from the Colorado River, defined as the quantity of water that is delivered to México above the amount the US is obligated to deliver under the 1944 treaty (1.5 million acre-feet yr^{-1}). This water represents "excess" water that is released from, or passed through, storage and conveyance facilities (dams and reservoirs) in the US. As defined, this "excess" water, proposed to be made available to the Salton Sea, has been delivered to México in only 14 yr since 1950. The amount of flood flows available in the future can only be speculative, but the Salton Sea Authority and US Bureau of Reclamation (2000a) presented predictions based on probability models. Not surprisingly, models showed that there may be a number of years in a row with no available flood flows, and that flood flow years may be clustered together—overall averaging one flood every 3 to 5 yr. The Colorado River is a very variable river, even with its many dams, reservoirs, and diversions.

The "excess" flood flows mentioned in No. 4 would be delivered to the Salton Sea by the Alamo River, Salt Creek, and Detention Channel #1 (also known as

the Coachella Evacuation Channel and Cleveland Street Spillway, at the north end of the Sea). The capacity of the Alamo River channel might be exceeded by these flood flows, but the Salton Sea Authority and US Bureau of Reclamation (2000a) does not discuss how to prevent or alleviate this problem. The Authority commented that scouring of the river bed might occur, with concomitant removal of plant and animal communities. Salt Creek might lose its wild population of desert pupfish, a possibility not mentioned by the Salton Sea Authority and US Bureau of Reclamation (2000a), as well as become both colder and more silty. The Salton Sea Authority and US Bureau of Reclamation (2000a) erroneously stated "Detention Channel #1 is dry the majority of the time and does not support aquatic resources;" the Authority therefore did not discuss any adverse effects of using this channel for flood flows. In fact, the lower part of the Cleveland Street Spillway has a constant flow of agricultural wastewater from just above the highway 111 and transcontinental railroad bridges; it supports a diverse population of plants, invertebrates, and fish, including desert pupfish (see many Tables; Oglesby pers. obs.). The Authority does not address the undoubted deleterious impacts on Delta wetlands of diverting even more water away from the Colorado River.

Phase 2 of the Salton Sea Restoration Project would involve one or more of the following: (1) expand the Enhanced Evaporation System; (2) export Salton Sea water out of the Salton Trough to the Gulf of California, to the Pacific Ocean near San Diego, or to Palen Dry Lake bed, and (3) import Central Arizona Salinity Interceptor water from Arizona through Yuma to the Salton Sea. The design life of all Phase 2 Alternatives would be around 100 years (Salton Sea Authority and US Bureau of Reclamation 2000a).

Because any Phase 2 actions would not take place for some 15–30 yr after Phase 1 is completed, they were not analyzed in detail in the Authority's 2000 Environmental Impact Report (Salton Sea Authority and US Bureau of Reclamation 2000a). Many potential impacts on the Salton Sea ecosystem and on the ecosystems of receiving waters were ignored.

At the third Salton Sea Symposium in January 2000 (Salton Sea Authority and US Bureau of Reclamation 2000b), the Authority unveiled its final report together with a draft Environmental Impact Report (Salton Sea Authority and US Bureau of Reclamation 2000a). There was a refreshing change in attitude about the Sea's condition. Milton Friend, lead federal scientist on the project was quoted: "Contrary to its putrid smell and off-putting look, the sea is not hopelessly polluted and is actually robustly healthy in many ways. What in some instances has been accepted dogma is now being revealed to be largely myth. Innuendo is now being challenged by data. The fish population is actually booming, pesticide concentrations in the water and sediment are minimal, and there is no evidence of bacteria in the sea that can harm humans." As discussed above, all these positive conclusions were well documented prior to the Authority's 2000 report.

The Authority's five alternatives have been actively opposed by many residents of the Salton Trough, San Diego, and elsewhere. Many worry that restoring the Salton Sea will require additional freshwater that is needed elsewhere; using any additional Colorado River water is now impossible. Residents especially oppose the Enhanced Evaporation System because of its visual impacts and are concerned that none of the alternatives would maintain the sport fishery or provide opportunities for enhanced recreation and economic growth. Many objections are based

on lack of knowledge of the ecosystem of the Salton Sea and on lack of understanding of the Authority's proposals. Some of the criticism and alternative proposals are remarkable for their lack of any factual foundation; several are totally infeasible on just engineering grounds. Some people are opposed to spending any additional money on the Salton Sea. These concerns are vetted especially through several World Wide Web sites devoted to the Salton Sea.

As discussions continue about the January 2000 report (Salton Sea Authority and US Bureau of Reclamation 2000a) virtually all attention has been paid only to dealing with the twin problems of maintaining an ecologically viable salinity and stabilizing the elevation of the Salton Sea. A few others, rarely listened to, have pointed out that other problems may, at least in the short run, be more important. Superintendent Horvitz of the Salton Sea State Recreation Area believes that excessive nutrient input must be controlled immediately to reduce eutrophication and hypoxia, though he believes that controlling increased salinity is also very important (Horvitz 2000).

A highly critical study was published by the Pacific Institute for Studies in Development, Environment, and Security, before the Authority issued its January 2000 report. The Pacific Institute strongly criticized the direction the Authority was taking (Cohen et al. 1999). Its major conclusion was that the current approach is seriously flawed for the following four interconnected reasons:

1. The current strategy of the Authority's Restoration Project (Salton Sea Authority and US Bureau of Reclamation 2000a) neither reflects nor satisfies the public interest. The public interest is the preservation and restoration of the Salton Sea ecosystem, but there is no evidence that the Restoration Project, focused only on salinity and elevation stabilization, will improve the ecosystem.
2. Decisions are being driven by arbitrary and unrealistic political timelines, not by scientific evidence. The Salton Sea Reclamation Act of 1998 and the Authority's January 2000 proposals do not draw upon scientific evidence and information. Detailed research on the current ecology of the Salton Sea began after the Authority chose its five alternatives. Much of the research discussed in the present review was not mentioned by the Authority.
3. The major problems may not be directly related to salinity, which is the focus of the current plan. The major crisis facing the Salton Sea at present, if there is a crisis, is the increased number of fish and bird die-offs, which most scientists do not see as being directly related to salinity. Rather, they see extreme eutrophication, high nutrient concentrations, and perhaps contaminants as proximal problems.
4. The focus on salinity distracts from other anthropogenic factors in the basin that are more directly linked to the ecological problems of the Salton Sea. The Authority's narrow focus excludes recognition and evaluation of the Sea's complex agricultural-ecological system, where natural factors (climate, elevation) and anthropogenic factors (land use) impact the Sea.

Cohen et al. (1999) presented the following principles for sustainability and equity:

1. The primary goal of any restoration plan must be to provide for a healthy ecological system and protect human health.

2. Any restoration plan should be firmly grounded in a scientific understanding of the ecology of the Salton Sea and related systems.
3. Any restoration plan should address all the water quality factors responsible for the current problems at the Salton Sea.
4. Parties responsible for the current problems facing the Salton Sea and beneficiaries of its restoration should bear an equitable share of the costs.
5. Any restoration plan must be compatible with region-wide water conservation and voluntary reallocation programs.
6. Any restoration plan for the Salton Sea must be compatible with protection and restoration of the Colorado River delta, northern Gulf of California, and other related ecosystems in the region.
7. The Restoration Project must be transparent, inclusive, and fully integrated with other actions impacting the Salton Sea.

Cohen et al. (1999) made a number of recommendations to improve the "restoration" process. Few of these were even hinted at in the January 2000 documents released by the Authority (Salton Sea Authority and US Bureau of Reclamation 2000a), which thus remain seriously flawed in their approach and conclusions.

Conclusions

The future of the Salton Sea as a viable, if strange, ecosystem with its splendid sport fishery and vital importance to migratory birds of the Pacific Flyway remains problematical. Current proposals may do little to protect this ecosystem.

The last word belongs to Jim Matthews of the Ontario CA *Inland Valley Daily Bulletin* 8 July 1999): "Rumors of the Salton Sea's death are greatly exaggerated. This fishery is thriving and healthy. It ranks as perhaps the single most productive fishery in California."

[Editor's Note: This last paragraph was written shortly before Larry Oglesby's death in April, 2001.]

Bibliography

References cited in the text are identified with an **M.**

Abbott, P. L. ed. 1979. Geological Excursions in the Southern California Area. San Diego St. Univ., San Diego CA. 217 pp.

Abbott, P. L. 1980. Provenance of Salton Dunes southwest of Salton Sea, California. pp. 77–80 in D. L. Fife and A. R. Brown, eds. Geology and Mineral Wealth of the California Desert. South Coast Geol. Soc., Santa Ana CA.

Abbott, P. L. 1996. Why Sturzstroms? in P. L. Abbott and D. Seymour, eds. Sturzstroms and Detachment Faults, Anza-Borrego Desert State Park, California. South Coast Geol. Soc. Guidebook #24, Santa Ana CA.

Abbott, P. L., and J. D. Cooper, eds. 1996. Field Conference Guidebook and Volume for the American Association of Petroleum Geologists Annual Convention, San Diego, California, May 1996. Pacific Sect., Amer. Assoc. Petrol. Geol., and Pacific Sect., Soc. Sediment. Geol. 475 pp.

Abbott, P. L., and D. Seymour, eds. 1996. Sturzstroms and Detachment Faults, Anza-Borrego Desert State Park, California. South Coast Geol. Soc. Guidebook #24, Santa Ana CA. 256 pp.

Abbott, R. T. 1952. A study of an intermediate snail host (*Thiara granifera*) of the oriental lung fluke (*Paragonimus*). US National Mus. Proc. 102: 71–116. **M**

Abbott, W. O. 1969. Salton Basin, a model for Pacific rim diastrophism. Geol. Soc. Amer. Sp. Pap. 12: 1 (abstract)

Ackermann, W. C., G. F. White, and E. B. Worthington, eds. 1971. Man-Made Lakes: Their Problems and Environmental Effects. Amer. Geophys. Union Monogr. 17. 847 pp.

Adams, V. D., and V. A. Lamarra, eds. 1983. Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Science, Ann Arbor MI. 697 pp.

Aerospace Corporation. 1971. Salinity Control Study, Salton Sea Project. Special Projects Groups, Adv. Planning Div., San Bernardino Operations. Aerospace Rep. ATR-71 (S9990)-5. 105 pp.

Aiken, R. 1999. 1980–1999 participation in fishing, hunting and wildlife watching: national and regional demographic trends. US Fish and Wildlife Service Rep. 96–5. 84 pp. **M**

Alicata, J. E. 1962. Life cycle and developmental stages of *Philophthalmus gralli* in the intermediate and final hosts. J. Parasit. 48: 47–54. **M**

Allen, C. R. 1957. San Andreas Fault zone in San Gorgonio Pass, southern California. Geol. Soc. Amer. Bull. 68: 315–349.

Al-Weshah, R. A. 2000. The water balance of the Dead Sea: an integrated approach. Hydrol. Processes, 14: 145–154. **M**

American Association of Petroleum Geologists, Pacific Section. 1973. Imperial Valley Regional Geology and Geothermal Exploration. Amer. Assoc. Petrol. Geol., Pacific Sect., Guidebook 30. Los Angeles CA. 56 pp.

American Geographical Society. 1906. The Salton Sink, Geographical Record. Geograph. Soc. Bull. 38: 561 pp.

Anastasiou, C. J. 1961. Fungi from salt lakes. I. A new species of *Clavariopsis*. Mycologia, 53: 11–16. **M**

Anastasiou, C. J. 1962. The Fungi of the Salton Sea, California: their Taxonomy, Biology, and Relationships. PhD dissertation, Rancho Santa Ana Botanic Garden, Claremont CA. 124 pp. **M**

Anastasiou, C. J. 1963. Fungi from Salt Lakes II. Ascomycetes and Fungi Imperfecti from the Salton Sea. J. Cramer, Weinheim. 33 pp. **M**

Anderson, D. W. 1999. A regional perspective for migratory bird resources of the Salton Sea area. Symp. Science Salton Sea Ecosystem Manage., Univ. Calif. Riverside, Riverside CA.

Anderson, D. W., L. R. DeWeese, and D. V. Tiller. 1977. Passive dispersal of California brown pelicans. Bird-Banding, 487: 228–238.

Anderson, D. W., L. A. Moreno, and K. Sturm. 2000. Both North American pelican species co-occupy habitats and share management conservation problems of the Colorado Delta region. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Anderson, S. H. 1983. Yuma Rail Recovery Plan. US Fish Wildlife Serv., Portland OR. 51 pp.

Anonymous. 1906. Controlling the Colorado River and the Salton Sea. Sci. Amer. 12 December 1906: 467–469.

Anonymous. 1929. Striped bass to be planted in Salton Sea. Calif. Fish Game, 15: 254–255. **M**

Anonymous. 1930a. Striped bass introduced in Salton Sea. Calif. Fish Game, 16: 50–51. **M**

Anonymous. 1930b. Salton Sea bass. Calif. Fish Game, 16: 338. **M**

Anonymous. 1931a. [An experiment was carried on in securing and the transportation of ghost shrimp and mud-fish from San Diego Bay to Salton Sea and planting the same. About 15,000 ghost shrimp and 500 mud-fish were successfully planted with very little loss.] Calif. Fish Game, 17: 98. **M**

Anonymous. 1931b. [striped bass plant in Salton Sea, October 1930]. Calif. Fish Game, 17: 97. **M**

Anonymous. 1932. Striped bass in Newport Bay. Calif. Fish Game 18: 57–58. **M**

Anonymous. 1949. Tenth Annual International Desert Cavalcade of Imperial Valley. Calexico Chronicle Press, Calexico CA. Unpaged.

Anonymous. 1958. The Salton Sea story. Outdoor Calif. 19 (12): 4–7, 13. **M**

Anonymous. 1959. Salton Sea, Unique Playground in the Desert. Brawley News, Brawley CA. 18 pp.

Anonymous. 1964. New fish—tilapia—now under study. Outdoor Calif. 25: 16.

Anonymous. 1971. Salton Sea. PG&E Progress, January 1971: 8.

Anonymous. 1986. The Salton Sea. Aqueduct. Metropolitan Water District, 52: 9–14.

Anonymous. 1988. Special section on results of the Salton Sea Scientific Drilling Project, California. J. Geophys. Res. B. Solid Earth Planets, 93: 12,953–13,186.

Anonymous. 1989. Acid river. Mexican industry is polluting California's waters, while U.S. officials watch. Calif. Lawyer, October 1989: 24–25. **M**

Anonymous. 1999a. Farming: hard look at low-value crops. Estuary, 8 (6): 4.

Anonymous. 1999b. Deciding about the Colorado River Delta: Rejuvenated Wetlands raise New Issues about where Flood Flows should go. River Report, Spring 1999: 4–9.

Apple, R. M., A. York, A. Pigniolo, J. H. Cleland, and S. Van Wormer. 1997. Archaeological Survey and Evaluation Program for the Salton Sea Test Base, Imperial County, California. Prepared by KEA Environmental for US Depart. Navy, Southwest Div., Naval Facilities Engineer. Command, San Diego CA.

Armitage, M. H. 1999. The euryhaline gobiid fish, *Gillichthys mirabilis* Cooper 1864, second intermediate host of the trematode, *Pygidiopsoides spindalis* Marin 1951. South. Calif. Acad. Sci. Bull. 98: 75–79.

Arnal, R. E. 1954. Preliminary report on the sediments and Foraminifera from the Salton Sea, southern California. Geol. Soc. Amer. Bull. 65: 1227–1228.

Arnal, R. E. 1958. Rhizopoda from the Salton Sea, California. Cushman Found. Foraminiferan Res. 9(2): 36–45. **M**

Arnal, R. E. 1961. Limnology, sedimentation, and microorganisms of the Salton Sea, California. Geol. Soc. Amer. Bull. 72: 427–478. **M**

Arndt, H. 1993. Rotifers as predators on components of the microbial web (bacteria, heterotrophic flagellates, ciliates)—a review. Hydrobiologia 255: 231–246. **M**

Axelrod, D. I. 1995. Paleobotanical history of western deserts. pp. 3–13 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Axen, G. J., and J. M. Fletcher. 1998. Late Miocene Pleistocene extensional faulting, northern Gulf of California, Mexico and Salton Trough, California. Internat. Geol. Rev. 40: 217–244. **M**

Axen, G. J., M. Grove, D. Stockli, O. M. Lovera, D. A. Rothstein, J. M. Fletcher, K. Farley, and P. L. Abbott. 2000. Thermal evolution of Monte Blanco dome: low angle normal faulting during Gulf of California rifting and late Eocene denudation of the eastern Peninsular Ranges. Tectonics, 19: 197–212.

Babcock, E. A. 1968. On the high density core of the Durmid Dome, Imperial Valley. Amer. Geophys. Union Trans. 49: 759. (abstract)

Babcock, E. A. 1971. Detection of active faulting using oblique infrared aerial photography in the Imperial Valley, California. Geol. Soc. Amer. Bull. 82: 3189–3196.

Babcock, E. A. 1974. Geology of the northeast margin of the Salton Trough, Salton Sea, California. Geol. Soc. Amer. Bull. 85: 321–332. **M**

Babcock, E. A., R. W. Rex, T. Meidav, and W. Randall. 1968. On the high density core of the Durmid Dome, Imperial Valley. Amer. Geophys. Union, Trans. 49(4): 759, (abstract V8).

Bailey, D. A. 1983. Enhancement of Habitats for the Yuma Clapper Rail and Desert Pupfish, in the Vicinity of the Salton Sea, California. Univ. Calif. Los Angeles Environ. Sci. Engineer. Rep. 83–52. Variously paginated.

Bain, M. S. 1993. Assessing impacts of introduced aquatic species—grass carp in large systems. Environ. Manag. 17: 211–224. **M**

Bainbridge, D. A., and R. A. Virginia. 1995. Desert soils and soil biota. pp. 59–69 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Bainbridge, D. A,, V. Wegrzyn, and N. Albasel. 1990. Selenium in California. Dry Lands Res. Inst., Univ. Calif. Riverside Rep. 88-01-J-WR, 90–9-WQ for St. Water Res. Control Bd. 2 vols.

Balch, A., and J. Balch. 1974. Ancient Lake Cahuilla's Fish Trappers. privately printed. 92 pp. **M**

Baldwin, J., L. Lewis, M. Payne, and G. Roquemore, eds. 1997. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA. 348 pp. **M**

Balling, S. S., and V. H. Resh. 1984. Life history variability in the water boatman, *Trichocorixa reticulata* (Hemiptera: Corixidae), in San Francisco Bay salt marsh ponds. Ann. Entomol. Soc. Amer. 77: 14–19. **M**

Barcelous, D. G. 1997. Selenium. J. Toxicol. Clin. Toxicol. 37: 145–172.

Barlow, G. W. 1958a. Daily movements of desert pupfish, *Cyprinodon macularius,* in shore pools of the Salton Sea, California. Ecology, 39: 580–587. **M**

Barlow, G. W. 1958b. High salinity mortality of desert pupfish, *Cyprinodon macularius*. Copeia, 1958: 231–232. **M**

Barlow, G. W. 1961. Social behavior of the desert pupfish, *Cyprinodon macularius*, in the field and in the aquarium. Amer. Midland Naturalist, 65: 339–359. **M**

Barlow, G. W. 1963. Species structure of the gobiid fish *Gillichthys mirabilis* from coastal sloughs of the eastern Pacific. Pacific Sci. 17: 47–72. **M**

Barlow, G. W., and V. L. De Vlaming. 1972. Ovarian cycling in longjaw gobies, *Gillichthys mirabilis*, from the Salton Sea. Calif. Fish Game, 58: 50–57. **M**

Barnard, J. L., and W. S. Gray. 1968. Introduction of an amphipod crustacean into the Salton Sea, California. South. Calif. Acad. Sci. Bull. 67: 219–232. **M**

Barnard, J. L., and W. S. Gray. 1969. Biogeographic relationships of the Salton Sea amphipod, *Gammarus mucronatus* Say. South. Calif. Acad. Sci. Bull. 68: 1–9. **M**

Barnes, I. 1970. Metamorphic waters from the Pacific tectonic belt of the West Coast of the United States. Science 168: 973–975.

Barnett, P. G. 1978. Imperial Valley: Land of Sunshine and Subsidies. Calif. Inst. Urban Studies, Davis CA. 77 pp.

Barnum, D. A. 2000. Population surveys and preliminary contaminant analysis of birds on the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Barrows, C. W. 1997. Habitat relationships of the Coachella Valley fringe-toed lizard (*Uma inornata*). Southwestern Naturalist, 42: 218–223.

Barrows, D. P. 1900. Ethno-Botany of the Cahuilla Indians. Univ. Chicago Press, Chicago IL. Reprinted 1967, Malki Museum, Banning CA.

Basch, P. F., G. Grodhaus, and J. J. Di Conza. 1975. Introduced schistosomiasis: evaluation as a public health hazard. Western J. Med. 122: 127–129. **M**

Bauriedel, T. M. 1990. The Effects of Salinity and Temperature on Oxygen Consumption in the Freshwater Snail *Thiara granifera mauiensis*. Senior thesis, Pomona College, Claremont CA. 41 pp. **M**

Bayly, I. A. E. 1972. Salinity tolerance and osmotic behavior of animals in athalassic saline and marine hypersaline waters. Ann. Rev. Ecol. Syst. 3: 233–268.

Bazdarich, M. 1998a. An economic analysis of the benefits of rehabilitating the Salton Sea. Inland Empire Econ. Databank Forecasting Center, A. Gary Anderson Grad. School Manag., Univ. Calif. Riverside. 6 pp. **M**

Bazdarich, M. 1998b. Testimony submitted in response to request from Subcommittee House Committee on Resources. Subcomm. Water and Power concerning H.R. 3267, the Sonny Bono Memorial Salton Sea Reclamation Act. 10 March 1998. 6 pp. **M**

Bazdarich, M. 1999. Water economics and the Salton Sea. Inland Empire Rev. 7 (2): 6 pp.

Bean, L. J. 1960. The Wanakik Cahuilla. Masterkey, 34: 111–119.

Bean, L. J. 1972. Mukat's People: the Cahuilla Indians of Southern California. Univ. Calif. Press, Berkeley CA. 201 pp. **M**

Bean, L. J. 1974. Social organization in native California. pp. 113–34 in L. J. Bean and T. King, eds. 'Antap: California Indian Political and Economic Organization. Ballena Press, Ramona CA.

Bean, L. J. 1978. Cahuilla. in R. F. Heizer, ed. Handbook of the Indians of North America. Vol. 8. Smithsonian Inst., Washington DC.

Bean, L. J., and L. J. Borgeault. 1989. The Cahuilla. Chelsea House Publ., New York City. 111 pp.

Bean, L. J. and W. M. Mason 1962. Diaries and Accounts of the Romero Expeditions in Arizona and California, 1823–1826. Desert Museum, Palm Springs CA.

Bean, L. J., and K. S. Saubel. 1972. Temalpakh (From the Earth): Cahuilla Indian Knowledge and Usage of Plants. Malki Museum Press, Morongo Indian Reservation, Banning CA. 225 pp. **M**

Bean, L. J., and K. S. Saubel. 1990. California Indian shamanism. Ballena Press Anthropol. Pap. #39. Ballena Press, Menlo Park CA.

Bean, L. J., and C. R. Smith. 1998. Cupeño. pp. 247–252. in White, P. M. and S. D. Fitt, eds. Bibliography of the Indians of San Diego County: the Kumeyaay, Diegeño, Luiseño, and Cupeño. Native Amer. Bibliog. Ser. #21. Scarecrow Press, Lanham MD.

Bean, L. J., S. B. Vane, and J. Young, eds. 1981. The Cahuilla and the Santa Rosa Mountain Region: Places and their Native American Association: a Review of Published and Unpublished Sources. US Bur. Land Manag. Calif. Desert Planning Prog. Prepared by Cultural Systems Research. 106 pp.

Bean, L. J., S. B. Vane, and J. Young. 1991. The Cahuilla Landscape: the Santa Rosa and San Jacinto Mountains. Ballena Press Anthropol. Pap. #37. Ballena Press, Menlo Park CA. 116 pp. **M**

Beatty, T. 1992. Balancing urban development and endangered species: the Coachella Valley Habitat Conservation Plan. Environ. Manag. 16: 7–19.

Beaty, P. R. 1985. Draft Environmental Impact Report, Introduction of Triploid Grass Carp for Aquatic Weed Control in the Coachella and Imperial Valleys, California. Coachella Valley Water and Imperial Irrigation Districts. 69 pp.

Beckwith, R. 1987. Population genetics of an introduced species: *Bairdiella icistius* in the Salton Sea. South. Calif. Acad. Sci. Bull. 86: 34–40. **M**

Bee, R. L. 1983. The Quechan. in A. Ortiz, ed. Handbook of North American Indians. Vol. 10. Smithsonian Inst. Washington DC.

Benson, S. M., M. Delamore, and S. Hoffman. 1993. Kesterson crisis. J. Irrigat. Drainage Engineer. 119: 471–483. (abstract) **M**

Bequaert, J. C., and W. B. Miller. 1973. The Mollusks of the Arid Southwest, with an Arizona checklist. Univ. Austin Press, Austin TX.

Bergey, E. A., S. F. Balling, J. N. Collins, G. A. Lamberti, and V. H. Resh. 1992. Dynamics of invertebrates within an extensive *Potamogeton pectinatus* bed of a California marsh. Hydrobiologia, 234: 15–24.

Berkstresser, C. F., Jr. 1969. Data for Springs in the Colorado Desert Area of California. Calif. Dept. Water Resources and US Geol. Surv., Water Resources Div. Open File Rep. 13 pp.

Berry, F. A. F. 1967. Role of membrane hyperfiltration on origin of thermal brines, Imperial Valley, California. Amer. Assoc. Petrol. Geol. Bull. 51: 454–455.

Berry, K. H., R. A. Rado, and P. D. Mack. 1995. The California Desert Conservation Area database for vegetation, wildlife, soils and hydrology. pp. 513–567 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Berthelson, G. 1988. A Parched Trail: Highway 86, a Road in Transition, Takes You Through the Steaming Heart of the Imperial Valley to Mexico. Going Places (May/June): 4 pp.

Bettaso, R. H., and J. N. Young. 1999. Evidence for freshwater spawning by striped mullet and the return of the Pacific tenpounder in the lower Colorado River. Calif. Fish Game, 85: 75–76. **M**

Beus, S. S., and M. Morales, eds. 1990. Grand Canyon Geology. Oxford Univ. Press, New York City, 518 pp. **M**

Biehler, S., and T. Lee. 1997. Final Report on a Resource Assessment of the Imperial Valley. Univ. Calif. Riverside, DLRI Rep. #10. 68 pp.

Biehler, S., and R. W. Rex. 1971. Structural geology and tectonics of the Salton Trough, southern California. pp. 30–42 in W. A. Elders, ed. Geological Excursions in Southern California. Univ. Calif. Riverside Museum Contrib. #1.

Biehler, S., R. L. Kovach, and C. R. Allen. 1964. Geophysical framework of the northern end Gulf of California structural province. pp. 126–143 in Marine Geology of the Gulf of California. Amer. Assoc. Petrol. Geol. Mem. 3.

Bijvelds, M. J. C., G. Flick, and S. E. W. Bonga. 1997. Mineral balance in *Oreochromis mossambicus*: dependence on magnesium in diet and water. Fish Physiol. Biochem. 16: 323–331. **M**

Bishop, J. 1993. Genetic Diversity Within and Between Populations of the Old World Prosobranchs *Thiara granifera* and *Thiara tuberculata*. Senior thesis, Pomona College, Claremont CA. 45 pp. **M**

Bitler, D. C., ed. 1919. The Imperial Valley, California, 1919. Imperial County Bd. Supervisors, El Centro CA. 34 pp.

Bitler, D. C., ed. 1920. The Imperial Valley, California, 1920. Imperial County Bd. Supervisors, El Centro CA. 34 pp.

Black, G. F. 1974. The party-boat fishery of the Salton Sea and the apparent effect of temperature and salinity on the catch of orangemouth corvina, *Cynoscion xanthulus*. Calif. Dept. Fish Game, Inland Fisheries Admin. Rep. 74–5. 14 pp.

Black, G. F. 1979. The current status and future management of the desert pupfish, *Cyprinodon macularius*, within California. Desert Fishes Council, Proc. 11th Ann. Symp. 47–48.

Black, G. F. 1980. Status of the desert pupfish, *Cyprinodon macularius* (Baird and Girard), in California. Calif. Dept. Fish Game Inland Fisheries Endangered Species Program Sp. Pub. 80–1. 42 pp. **M**

Black, G. F. 1981. Prognosis for water conservation and the development of energy resources at the Salton Sea—destruction or preservation of this unique ecosystem? pp. 363–382 in V. D. Adams and V. A. Lamarra, eds. Aquatic Resources Management of the Colorado River Ecosystem. Ann Arbor Science, Ann Arbor MI. **M**

Black, G. F. 1985. The Salton Sea sportfishery. Region 5 Info. Bull. 0010–5011985. Calif. Dept. Fish Game, May 1985. 43 pp.

Black, G. F. 1988. Description of the Salton Sea sport fishery, 1982–83. Calif. Dept. Fish Game, Inland Fisheries Admin. Rep. 88–9: 50 pp. (abstract)

Black, G. F., J. St. Amant, and K. R. Anderson. 1985. The Salton Sea sport fishery. Calif. Dept. Fish Game, Region 5 Info. Bull. 00010–5–1985. 43 pp. **M**

Blackburn, E. H. 1955. One Bit of Land: a Story of the Imperial Valley. Aladdin Books, New York City NY. 192 pp.

Blake, W. P. 1854. Ancient lake of the Colorado Desert. Amer. J. Sci. 17: 435–438. **M**

Blake, W. P. 1855. Preliminary Geological Report of the Expedition under Command of Lieutenant R. S. Williamson. US Topographical Engineers. US 33rd Congress, 1st Session. House Executive Document 129. Washington DC. 80 pp.

Blake, W. P. 1857. Geological Report. Part 2 of Pacific Railroad Survey Reports. US Exec. Doc. No 78. 32nd Congress, 2nd session. 1857. Reports of Explorations and Surveys to Ascertain the most Practicable and Economical Route for a Railroad From the Mississippi River to the Pacific Ocean. vol. 5. Washington DC. **M**

Blake, W. P. 1858a. Report of a Geological Reconnaissance in California; Made in Conjunction with the Expedition to Survey Routes in California, to Connect with the Surveys of Routes for a Railroad from the Mississippi River to the Pacific Ocean, Under the Command of Lieut. R. S. Williamson, Corps Top. Engineers. H, Ballière, London UK. 370 pp.

Blake, W. P. 1858b. Geological Report of California. H. Ballière, New York City NY. 336 pp.

Blake, W. P. 1908a. Destruction of the salt works in the Colorado Desert by the Salton Sea. Amer. Inst. Mining Engineer. Bull. 19: 81–82.

Blake, W. P. 1908b. Destruction of the salt works in the Colorado Desert by the Salton Sea. Amer. Inst. Mining Engineer. Trans. 38: 848–849.

Blake, W. P. 1914. The Cahuilla Basin and Desert of the Colorado. pp. 1–12 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L. **M**

Blake, W. P. 1915. Sketch of the region at the head of the Gulf of California. pp. 1–35 in H. T. Cory, ed. The Imperial Valley and the Salton Sink. J. J. Newbegin, San Francisco CA. **M**

Blaney, H. F. 1955. Evaporation from and stabilization of Salton Sea water surface. Amer. Geophys Union, Trans. 36: 633–649.

Boardman, T. S. 1998a. Roadlog: Geothermal resources in Coachella and Imperial Valleys. pp. 18–20 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. **M**

Boardman, T. S. 1998b. Heber Geothermal Field—an overview. pp. 129–137 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA.

Bodin, P., R. Bilham, J. Behr, J. Gomberg, and K. W. Hudnut. 1994. Slip triggered on southern California faults by the 1992 Joshua Tree, Landers, and Big Bear earthquakes. Seismol. Assoc. Amer. Bull. 84: 806–816.

Boellstorff, D. E., D. W. Anderson, H. M. Ohlendorf, and E. J. O'Beill. 1988. Reproductive effects of nest-making: studies in an American white pelican colony. Colonial Waterbirds, 11: 215–219.

Boley, J. L., J. P. Stimac, R. J. Weldon, and M. J. Rymer. 1994. Stratigraphy and paleomagnetism of the Mecca and Indio Hills, southern California. in Geological Investigations of an Active Margin. Geol. Soc. Amer. Cordilleran Section Guidebook. 1994. Reprinted as pp. 279–287 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Bolster, B. B. 1990. Desert pupfish: five year status report. Inland Fisheries Division, Calif. Dept. Fish Game, Rancho Cordova CA. 12 pp.

Bolton, H. E. 1930. Anza's California Expedition. 5 vols. Univ. Calif. Press, Berkeley CA.

Bolton, H. E. 1931. Font's Complete Diary. University of California Press, Berkeley CA.

Booth, W. 1997. Seeking salvation for the Salton Sea. Washington Post, 1 August 1997.

Bowen, S. H. 1980. Detrital nonprotein amino acids are the key to rapid growth of *Tilapia* in Lake Valencia, Venezuela. Science 207: 1216–1218.

Bower, C. A., J. R. Spencer, and L. O. Weeks. 1969. Salt and water balance, Coachella Valley, California. J. Irrigat. Drainage Div. Amer. Soc. Civil Engineer. Proc. 6437, IR1.

Bowers, S. 1891. The Cahuilla Indians. Pacific Monthly. 3 (6–7): 225–230. **M**

Bradford, G. R., D. Bakhtar, and D. Westcot. 1990. Uranium, vanadium, and molybdenum in saline waters of California. J. Environ. Qual. 19: 105–108. **M**

Brande, S., M. Turner, J. Heller, and O. Ben Yehuda. 1996. Statistical discrimination of sex in *Melanoides tuberculata* (Gastropoda: Thiaridae). Biol. J. Linn. Soc. 59: 87–112. **M**

Brandt, J. 1977. Birding at the Salton Sea. Western Tanager (Los Angeles Audubon Society), 43: 4–5.

Brannon, M. A. 1914. The action of Salton Sea water on vegetable tissues. pp. 71–78 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L.

Breuer, A. 1992. High-input Agriculture in the Western US: Imperatives for an Ecologically Sustainable Alternative. Senior thesis, Pomona College, Claremont CA. 30 pp. **M**

Bridges, T. S., and S. Heppel. 1996. Fitness consequences of maternal effects in *Streblospio benedicti* (Annelida: Polychaeta). Amer. Zool. 36: 132–146. **M**

Briggs, M. K., and S. Cornelius. 1997. Opportunities for ecological improvement along the lower Colorado River and Delta. Final report, Defenders of Wildlife, Washington DC, and National Park Service, US/Mexico Affairs Office, Las Cruces NM.

Brock, M. A. 1981. The ecology of halophytes in the south-east of South Australia. pp. 23–32 in W. D. Williams, ed. Salt Lakes. W. Junk, Publ. The Hague, Netherlands.

Brocksen, R. W., and R. E. Cole. 1972. Physiological responses of three species of fishes to various salinities. J. Fish. Res. Bd. Canada, 29: 399–405. **M**

Broussard, C. C., J. M. Randall, and M. C. Hoshovsky. 2000. Invasive Plants of California's Wildlands. Univ. Calif. Press, Berkeley CA. 360 pp. **M**

Broussard, M. L., ed. 1975. Deltas: Models for Exploration. Houston Geol. Soc., Houston TX. 555 pp.

Brown, G. W., Jr. 1968, 1974. Desert Biology. Academic Press, New York City. 2 vols.

Brown, J. S. 1920. Routes to desert watering places in the Salton Sea region, California. US Geol. Surv. Water-supply Pap. 490-A. 86 pp.

Brown, J. S. 1922. Fault features of the Salton Basin, California. J. Geol. 30: 217–226.

Brown, J. S. 1923. The Salton Sea Region, California: A Geographic, Geologic, and Hydrologic Reconnaissance with a Guide to Desert Watering Places. US Geol. Surv. Water Supply Pap. 497. 292 pp.

Brown, R. D. 1990. Quaternary deformation. The San Andreas Fault System, California. US Geol. Surv. Prof. Pap. 1515: 83–113. **M**

Bruehler, G., and A. de Peyster. 1999. Selenium and other trace metals in pelicans dying at the Salton Sea. Bull. Environ. Contam. Toxicol. 63: 590–597. **M**

Brumgardt, J. R., and L. L. Bowles. People of the Magic Waters: the Cahuilla Indians of Palm Springs. ETC Publ., Palm Springs CA. 122 pp.

Bryan, K. 1931. Physiographic study in the Salton Sea region. Geograph. Rev. 21: 153.

Bryant, W. A. 1987a. San Andreas and Hot Springs Faults, Bombay Beach area, Imperial County. Calif. Div. Mines Geol. FER-191.

Bryant, W. A. 1978b. Special Studies Zones Map, Frink Quadrangle, 1:24000 scale map. Calif. Div. Mines Geol.

Buckles, J., K. Kashiwase, and T. Krantz. 2000. Reconstruction of prehistoric Lake Cahuilla and early American settlement patterns in the Salton Sea basin using GIS. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract)

Buckley, C. P., M. E. Magee, and N. A. Hayden. 1977. Recent fractures along the northeast margin of the Salton Trough, Imperial County, California. Calif. Geol. March 30: 58–60.

Buddington, R. K. 1979. Digestion of an aquatic macrophyte by *Tilapia zillii*. J. Fish Biol. 15: 449–456.

Bumguardner, B. W., R. L. Colura, A. Henderson-Arzapalo, and A. F. Maciorowski. 1992. Culture of spotted seatrout, orangemouth corvina, and their hybrids. Calif. Fish Game 78: 105–115. **M**

Burgess, E. 1973. Geologists say state officials must face up to major decisions regarding development of geothermal resources. Calif. J. 4(2): 56–59.

Burgmann, R. 1991. Transpression along the southern San Andreas Fault, Durmid Hill, California. Tectonics, 10: 1152–1163. **M**

Burns, H. 1963. Salton Sea Story. 7th ed. revised. Riverside County Publ. Co., Riverside CA. 36 pp. **M**

Busch, D. I. 1996. Tides in Time. Douglas Isaac Busch Photo Dept., Santa Monica CA. 52 pp.

Butler, E. W., and J. W. Pick. 1982. Geothermal Energy Development: Problems and Prospects in the Imperial Valley of California. Plenum Press, New York City NY. 361 pp. **M**

Buwalda, J. P., and C. F. Richter. 1941. Imperial Valley earthquake of May 18, 1940. Geol. Soc. Amer. Bull. 71: 104–106.

Buwalda, J. P., and W. L. Stanton. 1930. Geological events in the history of the Indio Hills and the Salton Basin. Science 71: 104–106.

Byers, C. A. 1907. The possibilities of the Salton Sea. Popular Sci. Monthly, 70: 5–18. **M**

Cagle, F. 1998. Geomedicine in the Salton basin. pp. 169–187. in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. **M**

Caine, R. L. 1965. Is this Aztlan? Desert Mag. 28 (December): 18–20.

Calexico Chamber of Commerce. 1918. Calexico, California, in the Heart of the Imperial Valley, the Nile of America. Calexico Chamber Commerce, Calexico CA. 8 pp.

Calhoun, A. 1969. The Salton Sea can probably be saved, but—. Outdoor Calif. 39 (6): 2–3. **M**

California Bureau of Sanitary Engineering. 1958. Salton Sea Bacteriological Study: A Cooperative Study. Calif. Bur. Sanit. Engineer.

California Bureau of Sanitary Engineering. 1963. Salton Sea Bacteriological Study: A Cooperative Study. Calif. Bur. Sanit. Engineer.

California Department of Fish and Game, Region 5. 1965. Report on insecticide accumulation in Salton Sea fish. 26 pp.

California Department of Water Resources. 1970. Geothermal Wastes and the Water Resources of the Salton Sea Area. Calif. Dept. Water Resources Bull. 143-7: 126 pp. **M**

California Division of Beaches and Parks. 1966. Lower Colorado River and Desert Study: Cima Dome, Salton Sea, Whipple Mountains, Picacho, Mitchell Caverns. The Dept., Sacramento CA.

California Division of Oil and Gas. 1970. Compendium of Papers Presented at the Imperial Valley-Salton Sea Area Geothermal Hearing Conducted by the State of California Geothermal Resources Board and the California Legislative Joint Committee on Atomic Development and Space, October 1979. Calif. Div. Oil. Gas, Sacramento CA. Variously paginated.

California Energy Commission. 1981. Solar Salt Pond: Electric Power Generation at the Salton Sea. Executive Summary. Engineer. Environ. Div. Calif. Energy Comm. 31 pp.

California Regional Water Quality Control Board. 1991. Issue Paper on Salton Sea Water Quality. Calif. Regional Water Qual. Control Bd., Colorado River Basin, Palm Desert CA. 5 pp. **M**

California State Water Resources Control Board. 1975. Hearing on the petition of the Department of Fish and Game for review of orders Nos. 75–9, 75–10, 75–11 of the California Regional Water Quality Control Board, Colorado Basin Region, NPDES Permits Nos. CA0104710, CA0104434, and CA0104701, held in Coachella, 23 June 1975. Calif. St. Water Resources Cont. Bd. **M**

California State Water Resources Control Board. 1981. Toxic Substances Monitoring Program 1980. Water Quality Monitoring Rep. 81–8TS. 56 pp. + Appendices I-VI. **M**

California State Water Resources Control Board. 1984. Decision 1600: Alleged Waste and Unreasonable Use of Water by Imperial Irrigation District. Decision Regarding Misuse of Water by Imperial Irrigation District. Calif. St. Water Res. Control Bd. 71 pp. **M**

California State Water Resources Control Board. 1988. Decision/Order: Waste and Unreasonable Use of Water by Imperial Irrigation District. Order to Submit Plan and Implementation Schedule for Water Conservation Measures. Calif. St. Water Res. Control Bd. 46 pp. **M**

California Trade and Commerce Agency. 1999. Salton Sea Navy Base. California Trade and Commerce Agency, Sacramento CA. 2 pp.

Calleros, J. R. 1991. The impact on Mexico of the lining of the All-American Canal. National Resources J. 31: 829–838.

Capuzzo, J. M. 1979. The effects of halogen toxicants on survival, feeding, and egg production of the rotifer *Brachionus plicatilis*. Est. Coast. Mar. Sci. 8: 307–316.

Cardona, L., X. Torres, E. Gisbert, and F. Castello. 1996. The effect of striped grey mullet (*Mugil cephalus* L.) on freshwater ecosystems. Israeli J. Aquacult. Res. 48: 179–185. **M**

Carpelan, L. H. 1958. The Salton Sea. Physical and chemical characteristics. Limnol. Oceanogr. 3: 373–386. **M**

Carpelan, L. H. 1961a. History of the Salton Sea. Calif. Dept. Fish Game, Fish. Bull. 113: 9–15. **M**

Carpelan, L. H. 1961b. Physical and chemical characteristics [of the Salton Sea]. Calif. Dept. Fish Game, Fish. Bull. 113: 17–32. **M**

Carpelan, L. H. 1961c. Phytoplankton and plant productivity [of the Salton Sea]. Calif. Dept. Fish Game, Fish. Bull. 113: 33–42. **M**

Carpelan, L. H. 1961d. Zooplankton [of the Salton Sea]. Calif. Dept. Fish Game, Fish. Bull. 113: 49–61. **M**

Carpelan, L. H. 1967. Daily alkalinity changes in brackish water pools. Internat. J. Oceanol. Limnol. 1: 164–193.

Carpelan, L. H. 1995. Invertebrates of the California desert. pp. 275–283 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Carpelan, L. H. and R. H. Linsley. 1961a. The pile worm, *Neanthes succinea* (Frey and Leuckart). Calif. Dept. Fish Game, Fish Bull. 113: 63–76. **M**

Carpelan, L. H. and R. H. Linsley. 1961b. The spawning of *Neanthes succinea* in the Salton Sea. Ecology 42: 189–190. **M**

Carr, J. 1989. Palm Springs and the Coachella Valley. Amer. Geograph. Publ., Helena MT. 112 pp.

Castetter, E. F., and W. H. Bell. 1951. Yuman Indian Agriculture: Primitive Subsistance on the Lower Colorado and Gila Rivers. Univ. New Mexico Press, Albuquerque NM.

Cecil-Stephens, B. A. 1891. The Colorado Desert and its recent flooding. Amer. Geograph. Soc. Bull. 23: 367–377.

Chambers, W. T. 1995. California Desert Plan 1970–1980. pp. 569–592 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Chaniotis, B. N., J. M. Butler, Jr., F. F. Ferguson, and W. R. Jobin. 1980a. Thermal limits, desiccation tolerance, and humidity reactions of *Thiara* (*Tarebia*) *granifera mauiensis* (Gastropoda, Thiaridae), host of the Asiatic lung fluke disease. Carib. J. Sci. 16: 91–94. **M**

Chaniotis, B. N., J. M. Butler, Jr., F. F. Ferguson, and W. R. Jobin. 1980b. Presence of males in Puerto Rican *Thiara* (*Tarebia*) *granifera* (Gastropoda, Thiaridae), a snail thought to be parthenogenetic. Carib. J. Sci. 16: 95–97. **M**

Chartkoff, J. L., and K. K. Chartkoff. 1984. The Archaeology of California. Stanford Univ. Press. Stanford CA. 456 pp. **M**

Chase, J. S. 1923. Our Araby. Palm Springs and the Garden of the Sun. Star-News Publ. Co., Pasadena CA. 112 pp.

Chilcott, J. E. 2000. Review of Selenium Concentrations in Wetland Supply Channels in the Grassland Watershed. Calif. Environ. Protect. Agency, Regional Water Qual. Control Bd., Central Valley Region. 25 pp.

Chimbari, M. J., H. Madsen, and J. Ndamba. 1997. Laboratory experiments on snail predation by *Sargochromis codringtoni,* a candidate for biological control of the snails that transmit schistosomiasis. Ann. Trop. Med. Parasit. 91: 95–102. **M**

Chotiyaputta, C., and K. Hirayama. 1978. Food selectivity of the rotifer *Brachionus plicatilis* feeding on phytoplankton. Mar. Biol. 45: 105–111.

Christ, D. J. 1980. An Analysis of Water-Content Regulation in the Brackish-water Snail, *Thiara granifera mauiensis.* Senior thesis, Pomona College, Claremont CA. 31 pp. **M**

Christensen, R. J., and P. L. Abbott. 1980. Provenance of Salton dunes, southwest of the Salton Sea. pp. 409–413 in D. L. Fife and A. R. Brown, eds. Geology and Mineral Wealth of the California Desert. South Coast Geol. Soc., Santa Ana CA.

CIC Research, Inc. 1989. The economic importance of the Salton Sea sportfishery. A report to the California Department of Fish and Game. CIC Research, Inc., San Diego CA. **M**

Ciccotti, E., G. Marino, P. Pucci, E. Catalde, and S. Cataudella. 1995. Acclimation trial of *Mugil*

cephalus juveniles to fresh-water—morphological and biochemical aspects. Environ. Biol. Fishes, 43: 163–170. **M**

Cilliers, C. J. 1991. Biological control of water fern, *Salvinia molesta* (Salviniaceae), in South Africa. Agricult. Ecosyst. Environ. 37: 19–24. **M**

Clarke, A. O. 1976. Structural features of the Salton Trough as seen from Skylab. Calif. Geol. August 1976: 187–190.

Clarkson, R. W., and J. C. DeVos. 1986. The bullfrog, *Rana catesbeiana* Shaw in the lower Rio Colorado. J. Herpetol. 20: 42–49.

Clayton, R. N., L. J. P. Muffler, and D. E. White. 1968. Oxygen isotope study of calcite and silicate of the River Ranch No. 1 Well, Salton Sea geothermal field, California. Amer. J. Sci. 266: 968–979.

Cline, L. L. 1979. The Kwaaymii: Reflections on a Lost Culture. Imperial Valley College Mus., El Centro CA., Occas. Pap. #5.

Coachella Valley Mosquito and Vector Control District. 1997. Western equine encephalitis (and) St. Louis encephalitis. ⟨http://cvmvcd.orgea **M**

Coachella Valley Water District. 1985. Water and the Coachella Valley. Coachella Valley Water Dist., Coachella CA. 22 pp.

Coachella Valley Water District. 1993. Review 1991–93. Coachella Valley Water District, District Resources Office.

Coachella Valley Water District. 2000. Water and the Coachella Valley. Coachella Valley Water District. ⟨www.cvwd.org/water&cv.htm⟩ **M**

Cockerell, T. D. A. 1945a. The Colorado Desert of California: its origin and biota. Kansas. Acad. Sci. Trans. 48: 1–30.

Cockerell, T. D. A. 1945b. The Salton Sea. Kansas. Acad. Sci. Trans. 48: 37–39. **M**

Cockerell, T. D. A. 1946. The age of Lake Cahuilla. Science 103: 235.

Coe, J. J. 1970. Report in the Salton Sea Study. Calif. Dept. Water Resources. 9 pp.

Coe, J. J. 1981. Investigation under California Water Code Section 275 of use of water by Imperial Irrigation District. Calif. Dept. Water Resources. 209 pp. **M**

Coe, M. F., P. M. Detwiler, L. M. Harrington, and D. M. Dexter. 2000. Sampling the bottom-dwelling animals of the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract, modified) Center for Inland Waters, San Diego State University. ⟨www.sci.sdsu.edu/salton/SaltonSeaHomePage.html⟩ **M**

Cogswell, H. L. 1977. Water Birds of California. Univ. Calif. Press, Berkeley CA. 399 pp. **M**

Cohen, J. V. 1981, Certain Imperial Irrigation District land not subject to limitations of federal reclamation laws. Natural Resources J. 21: 925–933.

Cohen, M. J., J. I. Morrison, and E. P. Glenn. 1999. Haven or Hazard: the Ecology and Future of the Salton Sea. Pacific Inst. Studies Develop. Environ. Security, Oakland CA. 64 pp. **M**

Cohn, J. P. 2000. Saving the Salton Sea: researchers work to understand its problems and provide possible solutions. BioScience 50: 295–301. **M**

Cole, G. A. 1968. Desert limnology. pp. 423–486 in G. W. Brown, Jr., ed. Desert Biology. Vol. 1. Academic Press, New York City.

Coleman, G. A. 1929. A biological survey of the Salton Sea. Calif. Fish Game 15: 218–227. **M**

Collins, C. T., and K. L. Garrett. 1996. The black skimmer in California: an overview. Western Birds, 27: 127–135. (abstract)

Collins, C. W. 1911. Imperial County, California. Daily Standard Press, El Centro CA. 32 pp.

Colorado River Board of California. 1970. Need for controlling salinity of the Colorado River. Calif. Resources Agency, Colorado River Bd. 89 pp.

Colorado River Board of California. 1992. Report to the California Legislature on the Current Condition of the Salton Sea and the Potential Impacts of Water Transfers. Colorado River Bd. Calif. 39 pp.

Colorado River Wildlife Council. 1977. Endemic fishes of the Colorado River system: a status report. Endemic Species Comm., Colorado River Wildlife Council. 15 pp. **M**

Combs, G. F., C. Garbisu, B. C. Yee, D. E. Carlson, N. R. Smith, A. C. Magyarosy, T. Leighton, and B. B. Buchanan. 1996. Bioavailability of selenium accumulated by selenite-reducing bacteria. Biol. Trace Element Res. 52: 209–225. **M**

Comin, F. A., and T. G. Northcote, eds. 1990. Saline Lakes IV. Hydrobiologia, 197. Reprinted by Kluwer Acad. Publ., Boston. 308 pp.

Comité Técnico para la Preservación de la Vaquita y la Totoaba. 1993. Propuesta para la Declaración de Reserva de la Biósfera: Alto Golfo de California y Delta del Río Colorado. Comité Técnico para la Preservación de la Vaquita y la Totoaba, México DF. 80 pp.

Contreras-Arquieta, A. 1998. New records of the snail *Melanoides tuberculata* (Müller, 1774) (Gastropoda: Thiaridae) in the Cuatros Ciénegas Basin, and its distribution in the state of Coahuilla, Mexico. Southwestern Naturalist, 43: 283–286.

Cook, C. B., and G. T. Orlob. 1997. Field monitoring and hydrodynamic modeling of the Salton Sea, CA. pp. 659–664 in Wang, ed. Environmental and Coastal Hydraulics: Protecting the Aquatic Habitat. Proc. 27th Congress International Assoc. Hydraulic Research. **M**

Cook, C. B., G. T. Orlob, S. Breithaupt, J. D. Anderson, and J. Fellows. 1995. Salton Sea Project Phase I: Final Report. Modeling Group, Center Environ. Water Resources Engineer, Univ. Calif. Davis. 42 pp.

Cook, C. B., D. W. Huston, G. T. Orlob, I. P. King, and S. G. Schladow. 1998. Salton Sea Project Phase II Final Report: Data Collection and Analysis for Calibration and Verification of a Three-Dimensional Hydrodynamic Model. Prepared for Salton Sea Authority and California Department of Water Resources. Dept. Civil Environ. Engineer., Univ. Calif. Davis. Rep. 98–2. **M**

Cook, C. B., G. T. Orlob., and D. W. Huston. 2000. Three dimensional hydrodynamic modeling of the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA. 13–14 January 2000. (abstract) **M**

Coplan, T. B. 1972. Origin of geothermal waters in the Imperial Valley of southern California, in cooperative investigation of geothermal resources in the Imperial Valley area and their potential value for desalting water and other purposes. pp. E-1–33 in R. W. Rex et al., eds. Report to the US Bur. Reclam., Inst. Geophysics Planetary Physics, Univ. Calif. Riverside.

Cornett, J. W. 1989. Desert Palm Oasis. Palm Springs Desert Museum, Palm Springs CA. 48 pp. **M**

Cornett, J. W. 1995. Indian Uses of Desert Plants. Palm Springs Desert Museum, Palm Springs CA. 38 pp.

Cornett, J. W. 2000. Indians and Desert Animals. Nature Trails Press, Palm Springs CA. 64 pp. **M**

Corona, F. V., ed. 1993a. The San Andreas Fault System. 9th Thematic Conference on Geological Remote Sensing, Pasadena CA. **M**

Corona, F. V. 1993b. The San Andreas Fault of the Salton Trough region, California, as expressed in remote sensing data. pp. 69–73 in R. E. Reynolds and J. Reynolds, eds. Ashes, Faults and Basins. The 1993 Mojave Desert Quaternary Research Center Field Trip. San Bernardino County Mus. Assoc. Sp. Publ. 93–1. **M**

Corones, J., ed. 1993. Colorado Desert and Salton Trough Geology. San Diego Assoc. Geologists, San Diego CA. 1993 Field Trip Guide. 131 pp.

Cory, H. T. 1913. Irrigation and river control in the Colorado River delta. Amer. Soc. Civil Engineer. Trans. 76: 1204–1571. Reprinted in Cory, H. T. ed. The Imperial Valley and the Salton Sink. J. J. Newbegin, San Francisco CA. **M**

Cory, H. T., ed., 1915. The Imperial Valley and the Salton Sink. J. J. Newbegin, San Francisco CA. 61 pp and 1204–1571. **M**

Costa-Pierce, B. A. 1998a. Final Synthesis Document: Fish and Fisheries of the Salton Sea. Prepared for Salton Sea Authority by Institute of Marine Science, Univ. Southern Mississippi. Salton Sea Database Program, U. of Redlands, CA. ⟨www.institute.redlands.edu/salton/recon/index.aspx⟩ **M**

Costa-Pierce, B. A. 1998b. Tilapias of the Salton Sea, a marine lake in California. pp. 584–590 in K. Fitzsimmons, ed. **Tilapia Aquaculture.** Proc. 4th Internat. Symp. Tilapia in Aquaculture. Northeast Regional Agricult. Engineer. Serv. Cornell Univ., Ithaca NY. **M**

Costa-Pierce, B. A., and J. Butler. 1998. Fisheries biology and fish ecology of the Salton Sea. Prepared for the Salton Sea Authority by San Diego State Univ. Center for Inland Waters, San Diego CA. Salton Sea Database Program, U. of Redlands, CA.

Costa-Pierce, B. A., and R. W. Doyle. 1997. Genetic identification and status of tilapia regional strains in southern California. pp. 1–17 in B. A. Costa-Pierce and R. W. Doyle, eds. Tilapia Aquaculture in the Americas. vol. 1. World Aquaculture Society, Baton Rouge LA. **M**

Costa-Pierce, B. A., and R. Riedel. 2000. Fisheries ecology of the tilapias in subtropical lakes of the United States. pp. 1–20 in Tilapia Aquaculture in the Americas. vol. 2. World Aquaculture Society, Baton Rouge LA. **M**

Costa-Pierce, B. A., R. Riedel, J. Butler, L. Helvenston, and S. H. Hurlbert. 2000. Fisheries ecology

and fish biology of the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract). **M**

Coues, E. 1900. On the Trail of a Spanish Pioneer: the Diary and Itinerary of Francisco Garces in his Travels Through Sonora, Arizona, and California 1775–1776. 2 vols. Francis P. Harper, New York City.

Courtenay, W. R., Jr. 1997. Tilapias as non-indigenous species in the Americas: environmental, regulatory and legal issues. pp. 18–33 in B. A. Costa-Pierce and J. Rakocy, eds. Tilapia Aquaculture in the Americas. vol. 1. World Aquaculture Society, Baton Rouge LA.

Courtenay, W. R., Jr., and C. K. Robins. 1989. Fish introductions: good management, mismanagement, or no management? Rev. Aquat. Sci. 1: 159–172.

Courtenay, W. R., Jr. and J. Stauffer. 1990. The introduced fish problem and the aquarium fish industry. J. World Aquacult. Soc. 21: 145–159.

Courtois, L. A. 1976. Respiratory responses of *Gillichthys mirabilis* to changes in temperature, dissolved oxygen and salinity. Comp. Biochem. Physiol. 53A: 7–10. **M**

Cowles, R. B. 1934. Notes on the ecology and breeding habits of the desert minnow, *Cyprinodon macularius* Baird and Girard. Copeia 1934: 40–42. **M**

Cox, M. C. 1969. The Biology of the Euryhaline Water Boatman *Trichocorixa reticulata* (Guérin-Menéville) (Hemiptera: Corixidae). MS thesis, San Diego State College, San Diego CA. 84 pp.

Cox, T. J. 1972. The food habits of the desert pupfish (*Cyprinodon macularius*) in the Quitobaquito Springs, Organ Pipe Cactus National Monument, Arizona. J. Ariz.-Nev. Acad. Sci. 17: 35–37.

Craig, H. 1966. Isotopic composition and origin of the Red Sea and Salton Sea geothermal brines. Science 154: 1544–1548. **M**

Craig, H. 1969. Source fluids for the Salton Sea geothermal system. Amer. J. Sci. 267: 249–255.

Craig, J. F., and J. B. Kemper, eds. 1987. Regulated Streams: Advances in Ecology. Plenum, New York City, 431 pp.

Crane, W. B. 1914. The History of the Salton Sea. Historical Soc. South. Calif., Los Angeles, Publ. 9. 9 pp.

Crear, D. and I. Haydock. 1971. Laboratory rearing of the desert pupfish, *Cyprinodon macularius*. Fish. Bull. 69: 151–156. **M**

Crecelius, S. F. 1932. Report on the Probable Effect of Storage of Flood Waters of the Colorado and Gila Rivers on the Maximum and Minimum flow at the International Boundary and on Flood Control in the Colorado River Delta. Internat. Boundary Comm., US and Mexico.

Crisp, D. J., and J. D. Costlow. 1963. The tolerance of developing cirripede embyros to salinity and temperature. Oikos, 22–34. **M**

Crosby, S. W. 1929. Notes on a map of the Laguna Salada basin, Baja California, Mexico. Geograph. Rev. 19: 613–620.

Crowell, J. C., ed. 1975a. San Andreas Fault in Southern California: A Guide to the San Andreas Fault from Mexico to the Carrizo Plain. Calif. Div. Mines Geol. Special Rep. 118. 272 pp.

Crowell, J. C. 1975b. The San Andreas Fault in southern California. pp. 7–27 in J. C. Crowell, ed. San Andreas Fault in Southern California. Calif. Div. Mines Geol. Special Rep. 118.

Crowell, J. C. 1998. Fault map of the Salton Trough Region. pp. 13–4 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA.

Crowell, J. C., and B. Baca. 1979. Sedimentation history of the Salton Trough. pp. 101–110 in J. C. Crowell and A. G. Sylvester, eds. Tectonics of the Juncture between the San Andreas fault System and the Salton Trough, Southeastern California: A Guidebook for the Annual Meeting of the Geological Society of America, San Diego CA. Univ. Calif. Santa Barbara, Dept. Geol. Sci.

Crowell, J. C., and A. G. Sylvester, eds. 1979. Tectonics of the Juncture between the San Andreas Fault System and the Salton Trough, Southeastern California: A Guidebook for the Annual Meeting of the Geological Society of America, San Diego CA. Univ. Calif. Santa Barbara, Dept. Geol. Sci. 193 pp. **M**

Cruz-Rivera, E., and M. E. Hay. 2000. The effects of diet mixing on consumer fitness: macroalgae, epiphytes, and animal matter as foods for marine amphipods. Oecologia, 123: 252–264. **M**

Damiata, B. K., S. K. Parks, and L. Tien-Chang. 1986. Geophysical overview: Imperial Valley, southern California. pp. 116–133 in P. G. Guptill, R. W. Ruff, and E. M. Grath, eds. Geology of the Imperial Valley, California. South Coast Geol. Soc. Guidebook #14, Santa Ana CA.

Daszak, P., L. Berger, A. A. Cunningham, A. D. Hyatt, D. E. Green, and R. Speare. 1999. Emerging infectious diseases and amphibian population declines. Emerging Infectious Diseases, 5: 735–748. **M**

Daszak, P., A. A. Cunningham, and A. D. Hyatt. 2000. Emerging infectious diseases of wildlife—threats to biodiversity and human health. Science 287: 443–449. **M**

Date Palm Beach Corporation. 1930. Date Palm Beach on the Salton Sea: the World's most Unique Winter Resort. Date Palm Beach Corp. 8 pp.

Davidson, D. E. 1974. Wood-inhabiting and marine fungi from a saline lake in Wyoming. Brit. Mycol. Soc. Trans. 63: 143–149.

Davis, A. P. 1907. The new inland sea. National Geograph. Mag. 18 (1): 36–49. **M**

Davis, G. M., C. E. Chen, Z.-B. Kang, and Y.-Y. Liu. 1994. Snail hosts of *Paragonimus* in Asia and the Americas. Biomed. Environ. Sci. 7: 369–382. **M**

Davis, J. 1961. Trade Routes and Economic Exchange among the Indians of California. Univ. Calif. Archaeol. Surv. Report #54. Calif. Press, Berkeley CA.

Day, A. 1906. The inundation of the Salton Basin by the Colorado River and how it was caused. Sci. Amer. 14 April 1906: 310–312.

Deacon, J. E., and W. L. Linsley. 1974. Desert fishes. pp. 385–488 in G. W. Brown, Jr., ed. Desert Biology. Vol. 2. Academic Press, New York City.

Dean, P., C. Metzler, and A. Trujillo. 1997. Geology and Paleontology of the Anza-Borrego Region, California: Field Trip Guidebook for the National Association of Geoscience Teachers, Far Western Section. National Assoc. Geosci. Teachers, Far Western Sect. Variously paginated.

deBuys, W. 1999. Salt Dreams: Land & Water in Low-Down California. Photographs by J. Myers. Univ. New Mexico Press, Albuquerque NM. 307 pp. **M**

Defant, A. 1958. Ebb and Flow. Univ. Michigan Press, Ann Arbor MI. 121 pp. **M**

de la Peña, I. A., and I. I. Puente. 1979. The geothermal field of Cerro Prieto. pp. 20–35 in W. A. Elders, ed. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Muse. Contrib. 5.

de Stanley, M. 1976. The Salton Sea: Yesterday and Today. 7th printing, with revisions. Triumph Press, Los Angeles CA. 129 pp. **M**

Detwiler, P. M., M. M. Coe, and D. M. Dexter. 2000. The benthic invertebrates of the Salton Sea: distribution and seasonal dynamics. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract). **M**

Devries, D. R., R. A. Stein, J. G. Miner, and G. G. Mittelbach. 1991. Stocking threadfin shad—consequences for young-of-year fishes. Amer. Fish. Soc. Trans. 120: 368–381. **M**

Dexter, D. M. 1993. Salinity tolerance of the copepod *Apocyclops dengizicus* (Lepeschkin 1990), a key food chain organism in the Salton Sea, California. pp. 203–209 in S. H. Hurlbert, ed. Saline Lakes III. Kluwer Acad. Publ., Boston. **M**

Dexter, D. M. 1995. Salinity tolerance of *Cletocamptus deitersi* (Richard 1897) and its presence in the Salton Sea. South. Calif. Acad. Sci. Bull. 94: 169–171. **M**

Dexter, D. M., M. A. Tiffany, K. Reifel, and S. Hurlbert. 1999. A synthesis of our knowledge of the biological limnology of the Salton Sea. Prepared for the Salton Sea Authority by the Center for Inland Waters, San Diego State University, CA. 19 pp.

Dibblee, T. W. Jr. 1954. Geology of the Imperial Valley region, California. pp. 21–29 in R. H. Jahns, ed. Geology of Southern California. Calif. Div. Mines, Bull. 170.

Dibblee, T. W. Jr. 1986. Geology of the Imperial Valley region, California. pp. 1–14 in P. G. Guptill, R. W. Ruff, and E. M. Grath, eds. Geology of the Imperial Valley, California. South Coast Geol. Soc. Guidebook #14, Santa Ana CA.

Dibblee, T. W. Jr. 1997. Geology of the southeastern San Andreas Fault zone in the Coachella area, southern California. pp. 35–56 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA. **M**

Dill, S. W., and A. J. Cordone. 1997. History and status of introduced fishes in California, 1871–1996. Calif. Dept. Fish Game, Bull. 178: 1–414. **M**

Dill, W. A. 1944. The fishery of the lower Colorado River. Calif. Fish Game, 30: 109–211.

Dill, W. A., and C. Woodhill. 1942. A game fish for the Salton Sea, the ten-pounder *Elops affinis*. Calif. Fish Game, 28: 171–174. **M**

Dillon, J. T., and P. L. Ehlig. 1993. Displacement on the southern San Andreas Fault. in R. E. Powell,

R. E. Weldon, Jr., and J. C. Matti, eds. The San Andreas Fault System: Displacement, Palinspastic Reconstruction, and Geologic Evolution. Geol. Soc. Amer. Memoir 178. Reprinted as pp. 188–1205. in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Dixon, J. 1922. Rodents and reclamation in the Imperial Valley. J. Mammal. 3: 136–146.

Dobyns, H. F. 1981. From Fire to Flood: Historic Human Destruction of Sonoran Desert Riverine Oases. Ballena Press Anthropol. Papers 20. Ballena Press, Soccoro NM. 222 pp.

Doe, B. R., C. E. Hedge, and D. E. White. 1966. Preliminary investigation of the source of lead and strontium in deep geothermal brines underlying the Salton Sea geothermal area. Econom. Geol. 61: 462–483.

Doohan, M. 1973. An energy budget for adult *Brachionus plicatilis* Müller (Rotatoria). Oecologia, 13: 351–362.

Douglas, P. A. 1953. Survival of some fishes recently introduced into the Salton Sea, California. Calif. Fish Game, 39: 264–265.

Dowd, M. J. 1951. The Colorado River Flood Protection Works of Imperial Irrigation District: History and Cost. Imperial Irrigation District, El Centro CA. 70 pp.

Dowd, M. J. 1952. Problems of Imperial Irrigation District Relating to Salton Sea, Drainage and Quality of Water. Imperial Irrigation District, El Centro CA. 16 pp.

Dowd, M..J. 1953. Imperial Valley, Salton Sea and the Delta of the Colorado River. Presented to California Section, Amer. Water Works Assoc, Palm Springs CA. Imperial Irrigation District, El Centro, CA. 23 pp.

Dowd, M. J. 1955. Historic Salton Sea Provides Important Imperial Valley Drainage Outlet. Imperial Irrigation District, El Centro CA. 12 pp.

Dowd, M. J. 1956. History of Imperial Irrigation District and the Development of Imperial Valley. Imperial Irrigation District, El Centro CA. 94 pp. **M**

Dowd, M. J. 1960. Historic Salton Sea. Imperial Irrigation District, El Centro CA. 32 pp. **M**

Dower, R, 2000. Fishing the desert: when a vast lake suddenly formed and gradually evaporated in their desert, the Cahuilla people were forced to adapt. Amer. Archaeol. 4(4): 20–26.

Dozier, D. 1998. The Heart is Fire: The World of the Cahuilla Indians of Southern California. Heyday Books, Berkeley CA. 159 pp. **M**

Drake, D. J., ed. 1995. Selenium in the Environment: Essential Nutrient, Potential Toxicant. Proceedings National Symp. School Veterin. Medicine, Univ. Calif. Davis. 68 pp.

Dritschilo, W. 1983. An Analysis of Changes in Concentrations of Ions of Importance to the Salinity of the Salton Sea. Environ. Sci. Engineer. Univ. Calif. Los Angeles CA. Variously paginated.

Dritschilo, W., and D. Vander Pluym. 1984. An ecotoxicological model for energy development at the Salton Sea, J. Environ. Manag. 19: 15–30.

Drucker, P. 1937. Culture Element Distributions: V. Southern California. Univ. Calif. Anthropol. Records 1 (1).

Drucker, P. 1941. Culture Element Distributions: XVII. Yuman-Piman. Univ. Calif. Anthropol. Records 6 (3).

Dudgeon, D. 1989. Ecological strategies of Hong Kong Thiaridae (Gastropoda: Prosobranchia). Malacol. Rev. 22: 39–53. **M**

Dudgeon, D., and M. W. Yipp. 1985. The diets of Hong Kong freshwater gastropods. pp. 491–509 in B. Morton and D. Dudgeon, eds. The Malacofauna of Hong Kong and Southern China. Hong Kong Univ. Press, Hong Kong. **M**

Dudley, T., and B. Collins. 1995. Biological Invasions in California Wetlands. Pacific Institute for Studies in Development, Environment, and Security. Oakland CA. 64 pp.

Duncan, H. 1986. Pileworm Physiology. Research report, Pomona College, Claremont CA. 7 pp. **M**

Duncan, J., and R. Schmidt Sudman. 1984. Layperson's Guide to the Colorado River. Western Water Education Foundation, Sacramento CA. 16 pp.

Dundee, D. S., and A. Paine. 1977. Ecology of the snail, *Melanoides tuberculata* (Müller), intermediate host of the human liver fluke (*Opisthorchis sinensis*) in New Orleans, Louisiana. Nautilus, 91: 17–20. **M**

Dunham, J. B., and W. L. Minckley. 1998. Allozymic variation in desert pupfish from natural and artificial habitats: genetic conservation in fluctuating populations. Biol. Conserv. 84: 7–15. **M**

Dunn, J. 1977. The Salton Sea—a chronicle of the seasons. Western Tanager (Los Angeles Audubon Society) 43 May: 1–3.

Dunn, J., and P. Unitt. 1977. A Laysan albatross in interior southern California. Western Birds, 8: 27–28.

Duryea, E. Jr. 1903. Salton Sea menace. Out West, January 1903.

Eccles, L. A. 1979. Pesticide residues in agricultural drains, southeastern desert area, California. US Geol. Surv. Water. Res. Invest. 79–16.

Echelle, A. A., R. A. van den Bussche, T. P. Malloy, M. L. Haynie, and W. L. Minckley. 2000. Mitochondrial DNA variation in pupfishes assigned to the species *Cyprinodon macularius* (Atherinomorpha: Cyprinodontidae): taxonomic implications and conservation genetics. Copeia 2000: 353–364. **M**

Eddleman, W. R., R. E. Flores, and M. L. Lelgare. 1994. Black Rail (*Laterallus jamaicensis*). Birds of North America #123. Amer. Ornithol. Union, Philadelphia PA. 20 pp.

Edmondson, W. T., ed. 1959. Freshwater Biology. 2nd ed. John Wiley, New York City NY. 1248 pp. **M**

Eggold, B. T., and P. J. Motta. 1992. Ontogenetic dietary shifts and morphological correlates in striped mullet, *Mugil cephalus.* Environ. Biol. Fish. 34: 139–158. **M**

Eisler, R. 1985. Selenium Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. US Fish Wildlife Serv. Patuxent Wildlife Res. Center, Laurel MD. 57 pp.

Elder, H. S., and B. R. Murphy. 1997. Grass carp (*Ctenopharyngodon idella*) in the Trinity River, Texas. J. Freshwater Ecol. 12: 281–289. **M**

Elders, W. A. 1970. Crustal Spreading in Southern California: The Imperial Valley of California is a Product of Oceanic Spreading Centers Acting on a Continental Plate. Univ. Calif. Riverside Inst. Geophys. Planetary Phys. 11 pp.

Elders, W. A., ed. 1971. Geological Excursions in Southern California. Univ. Calif. Riverside Mus. Contrib. #1. 181 pp.

Elders, W. A., ed. 1979a. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Mus. Campus Contrib. 5. 108 pp. **M**

Elders, W. A. 1979b. Historical preface: man and the nature of the Colorado delta. pp. v-vii in W. A. Elders, ed. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Museum Campus Contrib. 5. **M**

Elders, W. A. 1979c. The geological background of the geothermal fields of the Salton Trough. pp. 1–19 in W. A. Elders, ed. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Mus. Campus Contrib. 5. **M**

Elders, W. A. 1979d. The Salton Trough as a delta. pp. 17–19 in W. A. Elders, ed. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Mus. Campus Contrib. 5.

Elders, W. A. 1984. Notes on geology, geothermics and ore genesis in the Salton Trough. Soc. Econom. Geol. Field Trip 24–26 February 1984, Univ. Calif. Riverside, UCR/IGPP85/4: 1–37.

Elders, W. A. 1985. The Salton Trough as a delta. pp. 24–26 in L. J. Herber, ed. Geothermal Energy of the Salton Trough. National Assoc. Geol. Teachers, Far Western Section.

Elders, W. A., ed. 1988. A Compendium of Reports on the Salton Sea Scientific Drilling Project. Center Geothermal Res., Inst. Geophys. Planetary Physics, Univ. Calif. Riverside.

Elders, W. A., and S. Biehler. 1975. Gulf of California rift system and its implication for the tectonics of western North America. Geology, 3: 85–87.

Elders, W. A., and J. H. Sass. 1988. The Salton Sea Scientific Drilling Project. J. Geophys. Res. 93: 12953–12968.

Elders, W. A., R. W. Rex, H. T. Meidav, P. T. Robinson, and S. Biehler. 1972. Crustal spreading in Southern California. Science 178: 15–24. **M**

Elders, W. A., S. Biehler, and I. A. de la Peña. 1979. Geology and geothermics of the Salton Trough road log. pp. 104–108 in W. A. Elders, ed. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Mus. Contrib. 5.

Elders, W. A., L. H. Cohen, and J. M. Mehegan. 1986a. Magmatism and volcanism in the Salton Trough. pp. 134–143 in P. G. Guptill, R. W. Ruff, and E. M. Grath, eds. Geology of the Imperial Valley, California. South Coast Geol. Soc. Guidebook #14, Santa Ana CA.

Elders, W. A., H. C. Lewis, and J. M. Mehegan. 1986b. Saline brines and ore-forming processes in the geothermal systems of the Salton Trough. pp. 134–143 in Geology of the Imperial Valley. Ann. Field Trip South Coast Geological Soc. 14.

Ely, L. L., Y. E. Enzel, V. R. Baker, and D. R. Cayan. 1993. A 5000-year record of extreme floods and climate change in the southwestern United States. Science 262: 410–412. **M**

Engelbert, E. A., and A. F. Scheuring, eds. 1982. Competition for California Water: Alternative Solutions. Univ. Calif. Press, Berkeley CA. 208 pp. **M**

England, A. S., and W. F. Laudenslayer, Jr. 1995. Birds of the California desert. pp. 337–372 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA. **M**

Epp, R. W., and W. M. Lewis, Jr. 1979. Sexual dimorphism in *Brachionus plicatilis* (Rotifera): evolutionary and adaptive significance. Evolution, 33: 919–912.

Epp, R. W., and P. W. Winston. 1977. Osmotic regulation in the brackish-water rotifer *Brachionus plicatilis* (Müller). J. Exp. Biol. 68: 151–156.

Epp, R. W., and P. W. Winston. 1978. The effects of salinity and pH on the activity and oxygen consumption of *Brachionus plicatilis* (Rotatoria). Comp. Biochem. Physiol. 59A: 9–12.

Evans, J. C., and E. E. Prepas. 1997. Relative importance of iron and molybdenum in restricting phytoplankton biomass in high phosphorous saline lakes. Limnol. Oceanogr. 42: 461–472. **M**

Evans, M. S., M. T. Arts and R. D.Robarts. 1996. Algal productivity, algal biomass, and zooplankton biomass in a phosphorus-rich, saline lake: deviations from regression model predictions. Canad. J. Fish. Aquat. Sci. 53:1048–1060.

Evans, N. A. 1975. Salt problems in the Colorado River. Univ. New Mexico School Law, Natural Resource J. 15: 55–62. **M**

Evens, J. G., G. W. Page, S. A. Laymon, and R. W. Stallcup. 1991. Distribution, relative abundance and status of the California black rail in western North America. Condor, 93: 952–966.

Evermann, B. W. 1916. Fishes of the Salton Sea. Copeia, 34: 61–63. **M**

Ezcurra, E., R. S. Felger, A. D. Russell, and M. Equihua. 1988. Freshwater islands in a desert sand sea: the hydrology, flora, and phytogeography of the Gran Desierto oases of northwestern Mexico. Desert Plants, 9: 35–44, 53–63.

Falciatore, A., M. Ribera d'Alcalà, P. Croot, and C. Bowler. 2000. Perception of environmental signals by a marine diatom. Science 288: 2363–2366. **M**

Farr, F. C., ed. 1918. The History of Imperial County, California. Elms and Frank, Berkeley CA. 526 pp. **M**

Fastnow, M. 1989. An Examination of the Distribution of *Thiara granifera* in Whitefield Creek, Salton Sea, California. Senior thesis, Pomona College, Claremont CA. 26 pp. **M**

Faulkner, J. 1998. An environmental reconnaissance of the Salton Sea; survey of algal toxins in the Salton Sea. Prepared for the Salton Sea Authority by Scripps Inst. Oceanog. Univ. Calif. San Diego, CA. Salton Sea Database Program, U. of Redlands, CA. ⟨www.institute.redlands.edu/salton/recon/index.aspx⟩ **M**

Federal Water Quality Administration. 1970. Salton Sea Water Quality and Ecological Management Considerations. Federal Water Quality Admin. Pacific Southwest Region. NTIS #PB-2533 691/0/XAB. 54 pp.

Feldmeth, C. R. 1980. Environmental assessment, biological inventories and impact assessment of the proposed borrow sites and Whitewater Marsh. Addendum to the Whitewater River Project. 56 pp. **M**

Felger, R. S., and M. B. Moser. 1985. People of the Desert and Sea, Ethnobotany of the Seri Indians. Univ. Arizona Press, Tucson AZ.

Ferrari, R. L., and P. Weghorst. 1997. Salton Sea 1995 Hydrographic GPS Survey. US Bureau of Reclamation, Tech. Serv. Center, Denver CO. available from National Tech. Info. Serv., Operat. Div., Springfield VA. **M**

Fialkowski, W., and W. A. Newman. 1998. A pilot study of heavy metal accumulations in a barnacle from the Salton Sea, southern California. Mar. Poll. Bull. 36: 138–143. **M**

Fielder, D. S., G. J. Purser, and S. C. Battagalene. 2000. Effect of rapid changes in temperature and salinity on availability of the rotifers *Brachionus rotundiformis* and *Brachionus plicatilis.* Aquaculture, 189: 85–99. (abstract) **M**

Finco, M. V., and G. F. Hepner. 1998. Modeling agricultural nonpoint source sediment yield in Imperial Valley, California. Photogram. Engineer. Remote Sens. 64: 1097–1105.

Finlayson, B. J., J. L. Nelson, and T. S. Lew. 1984. Biological, Chemical, and Physical Characteristics of *Hydrilla* Infested and Uninfested Waters of the Imperial Valley, California. Calif. Dept. Fish Game Environ. Sci. Admin. Rep. 84–3, 70 pp.

Fischer, P., ed. 1973. Imperial Valley Regional Geology and Geothermal Exploration. Amer. Assoc. Petrol. Geol., Soc. 56 pp.

Fish, G. R. 1955. Digestion and the production of sulphuric acid by Mollusca. Nature, 175: 733–734. **M**

Fish, J., and W. Cummings. 1972. A 50-dB increase in sustained ambient noise from fish (*Cynoscion xanthulus*). Amer. Acoustical Soc. Amer. J. 52: 1266–1270. **M**

Fleischer, R. C., G. Fuller, and D. B. Ledig. 1995. Genetic structure of endangered clapper rail (*Rallus longirostris*) populations in southern California. Conserv. Biol. 9: 1234–1243.

Flowerdew, M. W. 1985. Indices of genetic identity and distance in three taxa within the *Balanus amphitrite* Darwin complex (Cirripedia, Thoracica). Crustaceana, 49: 7–15. (abstract) **M**

Fong, P. P. 1991. The effects of salinity, temperature, and photoperiod on epitokal metamorphosis in *Neanthes succinea* (Frey et Leuckart) from San Francisco Bay. J. Exp. Mar. Biol. Ecol. 149: 177–190.

Forbes, J. D. 1965. Warriors of the Colorado: the Yumas of the Quechan Nation and Their Neighbors. Univ. Oklahoma Press, Norman OK

Ford, W. 1960. Harper's Well. Desert Mag. 23 (June): 43.

Ford, W. 1971. Treasure at Travertine Rock. Desert Mag. 34 (February): 10–12.

Forde, C. D. 1931. Ethnography of the Yuma Indians. Univ. Calif. Publ. Amer. Archaeol. Ethnol. 28 (4):83–278.

Fortner, B. 2000. Desert wetlands. Civil Engineer. 70: 58–61. **M**

Foster, N. M. C. 1972. Freshwater Polychaetes (Annelida) of North America. Biota Freshwater Ecosyst. Ident. Manual #4, US Environ. Protect. Agency, 1501–0368. 15 pp. **M**

Fox, C. K. 1936. The Colorado Delta: A Discussion of the Spanish Explorations and Maps, the Colorado River Silt Load, and its Seismic Effects of on the Southwest. Privately printed, Los Angeles CA. 75 pp.

Fox, R. O. 1970. *Corbicula* in Baja California. Nautilus, 84: 145.

Fradkin, P. L. 1981. A River No More: The Colorado River and the West. A. A. Knopf, New York City NY. 360 pp. **M**

Frankenberger, W. T., Jr. 1990. Dissipation of Soil Selenium by Microbial Volatilization at Kesterson Reservoir: Final Report. Univ. Calif. Riverside Dept. Soil Environ. Sic. Variously paginated.

Frankenberger, W. T., Jr., and R. A. Engberg, eds. 1998. Environmental Chemistry of Selenium. Marcel Dekker, New York City NY. 713 pp.

Frankenberger, W. T., Jr., U. Karlson, and K. E. Longley. 1990. Microbial Volatilization of Selenium from Sediments of Agricultural Evaporation Ponds: Final Report. Calif. St. Water Qual. Resources Bd. Sacramento CA. Variously paginated.

Franson, J. C., L. Creekmore, C. Meteyer, T. Rocke, and M. Wolcott. 2000. Eared grebe mortality at the Salton Sea in the 1900s: review of findings and new studies. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Free, E. E. 1914. Sketch of the geology and soils of the Cahuilla Basin. pp. 21–33 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L. **M**

French, R. L. 1984. Site-specific Research Conducted in Support of the Salton Sea Solar Pond Project: FY 1982 Report. Jet Propulsion Lab. Calif. Inst. Technol. Rep. 84–68. Pasadena CA.

Friend, M. 1999. Wastewater lakes: biodiversity asset or liability? North Amer. Lake Manag. Soc. Symp. Reno, NV. Center for Inland Waters, San Diego State University. ⟨www.sci.scsu.edu/salton/SaltonSeaHomePage.html⟩ **M**

Friend, M. 2000a. The state of the Salton Sea—opening comments. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam., Desert Hot Springs CA, 13–14 January 2000. (abstract)

Friend, M. 2000b. Salton Sea science—where do we go from here? Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract)

Friend, M. 2000c. Avian disease at the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam., Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Frisby, K. J. 1993. Imperial Valley: the Greening of a Desert. Imperial Valley College, Occas. Pap. #9. Desert Mus. Society, El Centro CA. 116 pp.

Frost, E. G., and D. L. Martin. 1982. Mesozoic-Cenozoic Tectonic Evolution of the Colorado River

Region, California, Arizona, and Nevada. Geol. Soc. Amer. Field Trip. Cordilleran Publ. San Diego CA. 608 pp.

Frost, E. G., L. A. Heizer, R. G. Blom, and R. L. Crippen. 1993. Western Salton Trough detachment system: its geometric role in localizing the San Andreas fault system. pp. 186–197 in F. V. Corona, ed. The San Andreas Fault System. 9th Thematic Conf. Geol. Remote Sensing, Pasadena CA.

Frost, E. G., S. C. Suitt, and M. Fattahipour. 1997. Emerging perspectives on the Salton Trough region with an emphasis on extensional faulting and its implications for later San Andreas deformation. pp. 57–97 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA. **M**

Fuis, G. S., and M. W. Kohler. 1984. Crustal structure and tectonics of the Imperial Valley region, California. pp. 1–14 in C. A. Rigsby, ed. The Imperial Basin, Tectonics, Sedimentation, and Thermal Aspects. Soc. Econom. Paleontol. Mineral. 40.

Fuis, G. S., and M. W. Kohler. 1985. Crustal structure and tectonics of the Imperial Valley region, California. pp. 95–107 in L. J. Herber, ed. Geothermal Energy of the Salton Trough. National Assoc. Geol. Teachers, Far Western Sect.

Fuis, G. S., W. D. Mooney, J. H. Healy, G. A. McMechan, and W. J. Lutter. 1981. Crustal structure of the Imperial Valley region. pp. 25–49 in The Imperial Valley, California, Earthquake of October 15, 1979. US Geol. Surv. Prof. Pap. 1254.

Fuller, P. M., L. G. Nico, and J. D. Williams. 1999. Nonindigenous Fishes Introduced into Inland Waters of the United States. Amer. Fish. Soc. Sp. Publ. 27. 613 pp.

Gaines, D. 1981. Mono Lake Guidebook. Kutsavi Books, Lee Vining CA. 113 pp. **M**

Gallegos, D., ed. 1980a. Cultural Resources Inventory of the Central Mojave and Colorado Desert Regions, California. Prepared by WESTEC Serv. for US Bur. Land Manage, Riverside CA. 149 pp.

Gallegos, D., ed. 1980b. Class II Cultural Resource Inventory of the East Mesa and West Mesa Regions, Imperial Valley, California. Vol I. Cult. Resources Publ. Anthropol. Hist. US Bureau Land Manag, Riverside CA.

Gallegos, D. 1986. Patayan II and Patayan III Occupation of IMP-4434 and IMP-5167, East Mesa, Imperial County, California. Report on file at the Southeast Information Center, Imperial Valley College Museum, El Centro CA.

Ganster, P., and A. Sweedler. 1988. The United States-Mexican Border Region. Keck Center Internat. Strategic Studies, Claremont CA. Essays Strategy Diplomacy #12. 30 pp.

Ganster, P., and H. Walter, eds. 1990. Environmental Issues of the California-Baja California Border Region. Border Environ. Res. Rep. #1. Southwest Center Environ Res. Policy, San Diego State Univ., San Diego CA. June 1996. 483 pp.

Ganster, P., and H. Walter, eds. 1996. Environmental Hazards and Bioresource Management in the United States-Mexico Borderlands. Univ. Calif. Los Angeles Latin Amer. Center Publ. Sped. Studies #3. 483 pp.

Gao, S, K., K. Tanji, D. W. Peters, and M. J. Herbel. 2000. Water selenium speciation and sediment fractionation in a California flow-through wetland system. J. Environ. Qual. 29: 1275–1283. **M**

Garate, D. 1994. Juan Bautista de Anza National Historic Trail. Southwest Parks Monuments Assoc., Tucson AZ. 15 pp.

Garrett, K., and J. Dunn. 1981. Birds of Southern California: Status and Distribution. Los Angeles Audubon Soc., Los Angeles CA. 408 pp. **M**

Garvey, J. E., N. A. Dingeldine, N. S. Donovan, and R. A. Stein. 1998. Exploring spatial and temporal variables with reservoir food webs: predictions for fish assemblages. Ecol. Applicat. 8: 104–120. **M**

Gates, P. G. 1909 Indian stone constructions near Salton Sea, California. Amer. Anthropol. 11: 322–323. **M**

Gatj, E., R. W. Ruff, R. McElwain, and M. L. Raub. 1986. Geology of the Salton Trough field trip road log. pp. 181–225 in P. G. Guptill, R. W. Ruff, and E. M. Grath, eds. Geology of the Imperial Valley, California. South Coast Geol. Soc. Guidebook #14, Santa Ana CA.

Gavin, T. A., R. A. Howard, and B. May. 1991. Allozyme variation among breeding populations of red-winged blackbirds: the California conundrum. Auk, 108: 602–611.

Giboda, M., S. A. Malek, and R. Correa. 1997. Human schistosomiasis in Puerto Rico: reduced

prevalence rate and absence of *Biomphalaria glabrata.* Amer. J. Trop. Med. Hyg. 57: 564–568. **M**

Gifford, E. W. 1931. The Kamia of Imperial Valley. Smithsonian Inst. Bur. Amer. Ethnol. Bull. 97. US Gov. Printing Office, Washington DC. 94 pp.

Gifford, E. W. 1933. The Cocopah. Univ. Calif. Publ. Amer. Archaeol. Ethnol. 31: 257–334.

Gilbert, C. H., and N. B. Scofield. 1898. Notes on a collection of fishes from the Colorado basin in Arizona. US National Mus. Proc. 20: 487–499.

Gillett, P., and P. R. Odens. 1974. Imperial Valley's Lost Gold. Southwest Printers, Yuma AZ. 54 pp.

Gillilan, W. 1971. The Imperial Wildlife Area (Wister Unit): how the DFG turned the scorched desert into a mecca for wildlife. Outdoor Calif. 32 (6): 14–16. **M**

Gilmore, T. D. 1986. Historic Vertical Displacements in the Salton Trough and Adjacent Parts of Southeastern California. US Geol. Surv. Open- file Rep. 86–380. 177 pp.

Gilmore, T. D., and R. O. Castle. 1983. Tectonic preservation of the divide between the Salton Basin and the Gulf of California. Geology, 11: 474–477.**M**

Glenn, E. P., R. S. Felger, A. Búrquez, and D. S. Turner. 1992. Ciénega de Santa Clara: endangered wetland in the Colorado River delta, Sonora, Mexico. Natural Resources J. 32: 817–824. **M**

Glenn, E. P., C. Lee, R. Felger, and S. A. Zengel. 1996. Effects of water management on the wetlands of the Colorado River delta, Mexico. Conserv. Biol. 10: 1175–1186.

Glenn, E. P., J. Garcia, P. Tanner, R. Congdon, and C. Luecke. 1999. Status of wetlands supported by agricultural drainage water in the Colorado River delta, Mexico. Hortscience 34: 39–45.

Glockhoff, C. 1998. Northern Gulf of California hydrocarbon. pp. 157–168 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. **M**

Glowacka, E., and F. A. Nava. 1996. Major earthquakes in Mexicali Valley, Mexico, and fluid extraction at Cerro Prieto geothermal field. Bull. Seismol. Soc. Amer. 86: 93–105. **M**

Gobalet, K. W. 1992. Colorado River fishes of Lake Cahuilla, Salton Basin, southern California: a cautionary tale for zooarchaeologists. South. Calif. Acad. Sci. Bull. 91: 70–83. **M**

Gobalet, K. W. 1994. Additional archaeological evidence for Colorado River fishes in the Salton Basin of southern California. South. Calif. Acad. Sci. Bull. 93: 38–41. **M**

Goldberg, D. 1979. Archaeological Survey Report for Category 4B and 5 Projects. Report on Bicentennial Monument Site, Imperial County California. Report on file with Caltrans District 11, San Diego CA.

Goldsmith, M. 1971a. Salinity Control Study, Salton Sea Project. Aerospace Corp., San Bernardino Operations, Aerospace Rep. ATR-71 (S9990)-5. 105 pp.

Goldsmith, M. 1971b, Geothermal Resources in California: Potentials and Problems. Calif. Inst. Technol. Environ. Quality Lab. Rep. #5. 45 pp.

Goldsmith, M. 1973. Salton Sea. California's little orphan ocean. Western Tanager (Los Angeles Audubon Society) 40 (Sept./Oct.).

Goldsmith, M. 1976. Geothermal development and the Salton Sea. Calif. Inst. Tech. Environ. Quality Lab., Memorandum #17.

Gómez, A., and M. Serra. 1995. Behavioral reproductive isolation among sympatric strains of *Brachionus plicatilis* Müller 1786: Insights into the status of this taxonomic species. Hydrobiologia, 313: 111–119. **M**

Gómez, A., and T. W. Snell. 1996. Sibling species and cryptic speciation in the *Brachionus plicatilis* species complex (Rotifera). J. Evol. Biol. 9: 953–964. **M**

Gómez, A., M. J. Carmona, and M. Serra, 1997. Ecological factors affecting gene flow in the *Brachionus plicatilis* complex (Rotifera). Oecologia, 111: 350–356. **M**

González, M. R., C. M. Hart, J. R. Verfaillie, and S. H. Hurlbert. 1998. Salinity and fish effects on Salton Sea microecosystems: water chemistry and nutrient cycling. Hydrobiologia, 381: 105–128. **M**

Gorsline, D. S. 1965. Annual Summary Report of Geological Studies of the Colorado Delta. Univ. South. Calif. Dept. Geol. Rep. 65–3. 16 pp.

Gorsline, D. S. 1967. Sedimentologic Studies of the Colorado Delta. Univ. South. Calif. Dept. Geol. Rep. 67–1. 89 pp.

Gosselin, L. A., and P. Qian. 1997. Can bactivory alone sustain larval development in the polychaete *Hydroides elegans* and the barnacle *Balanus amphitrite*? Mar. Ecol. Prog. Ser. 161: 93–103. **M**

Grabau, A. W. 1920. Formation of the Salton Sink by the Colorado delta. pp. 146–151 in Principles of Salt Deposition. McGraw-Hill, New York City NY.

Grannell, R. B. 1985. Land deformation in the Salton-Mexicali Trough. pp. 136–139 in L. J. Herber, ed. Geothermal Energy of the Salton Trough. National Assoc. Geol. Teachers, Far Western Sect.

Grant, G. S., and N. Hogg. 1976. Behavior of late-nesting black skimmers at Salton Sea, California. Western Birds 7: 73–80. (abstract)

Greeley, R., ed. 1978. Aeolian Features of Southern California: A Comparative Planetary Geology Guidebook. National Aeronaut. Space Admin. Washington DC. 254 pp.

Green, K. E. 1988. Salton Basin regional setting. pp. 1–6 in S. M. Testa and K. E. Green, eds. Geologic Field Guide to the Western Salton Basin Area. Amer. Inst. Prof. Geologists.

Gress, F., et al. 1973. Reproductive failure of double-crested cormorants in California and Baja California. Wilson Bull. 85: 197–208.

Grinnell, J. 1908. Birds of a voyage on Salton Sea. Condor, 10: 185–191. (abstract) **M**

Grinnell, J. 1914. An account of the mammals and birds of the lower Colorado Valley. Univ. Calif. Publ. Zool. 12: 51–294.

Grinnell, J. 1928. A distribution summation of the ornithology of Lower California. Univ. Calif. Publ. Zool. 1–300.

Grinnell, J., and A. H. Miller. 1944. The Distribution of the Birds of California. Cooper Ornithological Club, Pacific Avifauna 27. Berkeley CA. 608 pp. **M**

Grubbs, D. K. 1964. Ore-bearing magmatic and metamorphic brine from the Salton Sea volcanic domes geothermal area, Imperial County, California. Virginia J. Sci. 15: 333.

Grunsky, C. E. 1907. The Lower Colorado River and the Salton Basin. Amer. Soc. Civil Engineer. Trans. 59.

Guptill, P. G., R. W. Ruff, and E. M. Grath, eds. 1986. Geology of the Imperial Valley, California. South Coast Geol. Soc. Guidebook #14, Santa Ana CA. 225 pp.

Haack, V. 1959. The Salton Sea. Collector (Sacramento Conchological Society), 5: 1–4.

Haar, S. V., and I. P. Cruz. 1979. Hybrid transform faults and fault intersections in the southern Salton Trough geothermal area, Baja California, Mexico. pp. 95–100 in W. A. Elders, ed. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Mus. Contrib. 5.

Hagar, J., and J. Garcia. 1988. A review of the potential biological responses to salinity changes in the Salton Sea. in Problems and Potential Solutions at Salton Sea. Prepared for Meyer Resources Inc., Davis CA, by BioSystems Analysis, Sausalito CA. **M**

Hamilton, W. B. 1966. The geology of the Salton Trough. Calif. Div. Mines Geol. Bull. 191: 73–76.

Hamman, R. L., J. E. Johnson, and H. M. Tyus. 1994. Colorado squawfish. pp. 364–366 in C. G. Thelander, D. C. Pearson, and G. E. Olson, eds. Life on the Edge: A Guide to California's Endangered Natural Resources: Wildlife. Hey Day Books, Berkeley CA. **M**

Hammer, U. T., ed. 1983. Saline Lakes II. Proc. 2nd Ann. Symp. Athalassic (Inland) Saline Lakes. Hydrobiologia 105. Reprinted by W. Junk, Boston. 263 pp.

Hammer, U. T. 1986. Saline Lake Ecosystems of the World. W. Junk, Publ., Boston. 616 pp. **M**

Hampton, P. 1991. California's Salton Sea faces grave peril. Gannett News Service, 6 March 1991.

Hanna, G. D. 1966. Introduced molluscs of western North America. Calif. Acad. Sci. Occas. Pap. 48: 1–108.

Hansen, B., T. Wernberg-Møller, and L. Wittrup. 1997. Particle grazing efficiency and specific growth efficiency of the rotifer *Brachionus plicatilis* (Müller). J. Exp. Mar. Biol. Ecol. 215: 217–233. **M**

Hansen, D. 1998. Selenium removal by constructed wetlands: role of biological volatilization. Environ. Sci. Technol. 32: 591–597. **M**

Hanson, J. A. 1970. Salinity tolerances for Salton Sea fishes. Calif. Dept. Fish Game, Admin. Rep. 70–2. (abstract). **M**

Hanson, J. A. 1972. Tolerance of high salinity by the pileworm, *Neanthes succinea,* from the Salton Sea, California. Calif. Fish Game, 58: 152–154. **M**

Hargreaves, W. R. 1968. Larval development of *Nereis succinea* in concentrated Salton Sea water. Research report, Pomona College, Claremont CA. 28 pp. **M**

Harmon, C. 1969. Source fluids for the Salton Sea geothermal system. Amer. J. Sci. 267: 249–255.

Harrigan, B. A., ed. 1926. Imperial County, California. Imperial County Bd. Supervisors, El Centro CA. 16 pp.

Harrigan, B. A., ed. 1930. Imperial County, California: America's Winter Garden. Imperial County Bd. Trade, El Centro CA. 32 pp.

Harris, E. 1975. Bibliography of the Imperial Valley and its Environs. San Diego St. Univ. Press, San Diego CA. 153 pp.

Harris, T. 1991. Death in the Marsh. Island Press, Washington DC. 245 pp. **M**

Hart, C. M. 1994. Salinity and Fish Effects on Salton Sea Invertebrates: a Microcosm Experiment. MS thesis, San Diego State Univ., San Diego CA. 102 pp.

Hart, C. M., M. R. González, E. P. Simpson, and S. H. Hurlbert. 1998. Salinity and fish effects on Salton Sea microecosystems: zooplankton and nekton. Hydrobiologia, 381: 129–152. **M**

Hart, J. 1996. Storm Over Mono: the Mono Lake Battle and the California Water Future. Univ. Calif. Press, Berkeley CA. 211 pp. **M**

Hartman, O. 1936. New species of polychaetous annelids of the family Nereidae from California. US National Mus. Proc. 83: 467–480. **M**

Hauser, L., G. R. Carvalho, R. N. Hughes, and R. E. Carter. 1992. Clonal structure of the introduced freshwater snail *Potamopyrgus antipodarum* (Prosobranchia: Hydrobiidae) as revealed by DNA fingerprinting. Proc. Roy. Soc. London, B 249: 19–25. **M**

Hauser, W. J. 1974. Biological control of aquatic vegetation in the lower Colorado River Basin. Univ. Calif. Riverside CA, Imperial Valley Station, 3rd Interim Rep.

Hauser, W. J. 1975a. An unusually fast growth rate for *Tilapia zillii.* Calif. Fish Game, 61: 54–56. **M**

Hauser, W. J. 1975b. Can tilapia replace herbicides? Cal-Neva Wildlife Trans. 6: 44–50. **M**

Hauser, W. J. 1975c. *Tilapia* as biological control agents for aquatic weeds and noxious aquatic insects in California. Proc. Ann. Conf. Calif. Mosquito Control Assoc. 43: 51–53.

Hauser, W. J. 1977. Temperature requirements of *Tilapia zillii.* Calif. Fish Game, 63: 228–233. **M**

Hauser, W. J., and E. F. Legner. 1975. Biological control of aquatic weeds in the lower Colorado River basin. Univ. Calif., Riverside, Dept. Biol. Control, Ann. Rep. 48 pp. **M**

Hayden, R. P., and R. O. Rinnyo. 1963. Introduction of *Palaemonetes paludosus,* a freshwater shrimp, into the lower Colorado River. Calif. Fish Game, 49: 304–306. **M**

Haydock, I. 1971. Gonad maturation and hormone-induced spawning of the Gulf croaker, *Bairdiella icistia.* Fish. Bull. 69: 157–189. **M**

Haydock, I., and D. Crear, 1971. Research in spawning and rearing the Gulf croaker. Amer. Fish Farmer, 2: 16–21.

Hayes, D. L. 1991. The All-American Canal lining project: a catalyst for rational and comprehensive groundwater management on the United States-Mexico border. Natural Resources J. 31: 803–827.

Hays, W. H. 1958. Structure of the central Mecca Hills, Riverside County, California. Geol. Soc. Amer. Sp. Pap. 12: 1687.

Heber, A. H. 1904. Address of Hon. A. H. Heber, President of the California Development Company, to the Settlers of Imperial Valley in Support of the Water and Property Rights owned by the Company in the Valley at Imperial, California. 25 July 1904. South. Calif. Printing Co., Los Angeles Ca. 61 pp.

Hedgpeth, J. H. 1959. Some preliminary considerations of the biology of inland mineral waters. Arch. Oceanogr. Limnol. Suppl. xi: 125–129.

Heffernan, W. T. 1930. "Personal Reflections" of the Early History of Imperial Valley. Calexico Chronicle. 22 pp. bound with Rockwood 1918.

Heitmeyer, M. E., D. P. Connelly, and R. L. Pederson. 1989. The Central, Imperial, and Coachella valleys of California. pp. 475–504 in L. M. Smith, R. L. Pederson, and R. M. Kiminski, eds. Habitat Management for Migrating and Wintering Waterfowl in North America. Texas Univ. Press, Lubbock TX.

Heizer, R. F. 1974. An early Cahuilla ethnographic sketch [1854 Report of C. S. Lovell]. Master Key 48 (1):14–21.

Helgeson, H. C. 1968. Geologic and thermodynamic characteristics of the Salton Sea geothermal system. Amer. J. Sci. 266: 129–166. **M**

Heller, J., and S. Ehrlich. 1995. A fresh-water prosobranch, *Melanoides tuberculata,* in a hydrogen-sulfide stream. J. Conchol. 35: 237–264. **M**

Heller, J., and V. Farstey. 1990. Sexual and parthenogenetic populations of the fresh-water snail *Melanoides tuberculata* in Israel. Israel J. Zool. 37: 75–87. **M**

Hely, A. G., and E. L. Peck. 1964. Precipitation, Runoff, and Water Loss in the Lower Colorado River-Salton Sea Area. US Geol. Surv. Prof. Pap. 486-B. 16 pp.

Hely, A. G., G. H. Hughes, and B. Irelan. 1966. Hydrologic Regimen of Salton Sea, California: Water

Resources of Lower Colorado-Salton Area. A Study of the Variations in Water Level and Water Quality and their Causes. US Geol. Surv. Prof. Pap. 486-C: C1-C2. 32 pp. **M**

Henderson, R. P., and G. W. Page. 1979. The California interior. pp. 475–505 in L. M. Smith, R. L. Pederson, and R. M. Kaminski, eds. Habitat Management for Migrating and Wintering Waterfowl in North America. Texas Univ. Press, Lubbock TX.

Henderson, T. 1968. Imperial Valley. Neyenesch Printers, San Diego CA. 240 pp.

Hendricks, L. J. 1961a. The threadfin shad, *Dorosoma petenense* Günther, [in the Salton Sea]. Calif. Dept. Fish Game, Fish. Bull. 113: 93–94. **M**

Hendricks, L. J. 1961b. The striped mullet, *Mugil cephalus* Linnaeus [in the Salton Sea]. Calif. Dept. Fish Game, Fish. Bull. 113: 95–104. **M**

Hendrickson, D. A., and W. L. Minckley. 1985. Cienegas—vanishing climax communities of the American southwest. Desert Plants, 6: 131–175.

Hendrickson, D. A., and A. V. Romero. 1989. Conservation status of desert pupfish, *Cyprinodon macularius,* in Mexico and Arizona. Copeia 1989: 478–483. **M**

Henry, A. J. 1907a. Salton Sea and the rainfall of the southwest. National Geograph. Mag. 18 (4): 244–248. **M**

Henry, A. J. 1907b. The possibilities of Salton Sea. Pop. Sci. Monthly, 70: 5–18.

Henry, D. P., and P. A. McLaughlin. 1975. The barnacles of the *Balanus amphitrite* complex (Cirripedia, Thoracica). Zool. Verhandl. 141: 3–254. **M**

Herber, L. J., ed. 1985. Geology and Geothermal Energy of the Salton Trough: Guidebook for Far Western Sect., National Assoc. Geol. Teachers. 171 pp.

Herbst, D. B. 1999. Biogeography and physiological adaptations of the brine fly genus *Ephydra* (Diptera: Ephydridae) in saline waters of the Great Basin. Great Basin Naturalist, 59: 127–135. **M**

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissoidea) in the Great Basin, western United States. Part I. Genus *Pyrgulopsis.* Veliger, 41: 1–132. **M**

Hershler, R. 1999. A systematic review of the hydrobiid snails (Gastropoda: Rissoidea) the Great Basin, western United States. Part II. Genera *Colligyrus, Eremopyrgus, Fluminicola, Pristinicola,* and *Tryonia.* Veliger, 42: 306–337.

Herzig, C. T., and D. C. Jacobs. 1994. Cenozoic volcanism and 2-state extension in the Salton Trough, southern California and northern Baja California. Geology, 22: 991–994. **M**

Herzig, C., A. Carrasco, T. Scar, G. Murray, D. Rightmer, J. Lawrence, Q. Milton, and T. Wirtha. 1995. Neogene stratigraphy of the Borrego Mountain area, Anza-Borrego Desert State Park, California. pp. 1132–1136 in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Association of Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol., San Diego CA,

Hickman, J. C., ed. 1993. The Jepson Manual: Higher Plants of California. Univ. California Press, Berkeley CA. 1400 pp.

Hilgard, E. W. 1902. Lands of the Colorado Delta in the Salton Basin. Agricult. Exp. Sta., Univ. Calif., Berkeley Bull. #140. 51 pp.

Hill, D. P., P. Mowinckle, and L. G. Peake. 1975. Earthquakes, active faults, and geothermal areas in the Imperial Valley, California. Science 188: 1306–1308.

Hill, D. P., J. P. Eaton, and L. M. Jones. 1990. Seismicity, 1980–86. US Geol. Surv. Prof. Pap. 1515. The San Andreas Fault System, California. Reprinted as pp. 150–186. in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds.1997. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Hilton, J. 1945. Where barnacles grow on the sage. Desert Mag. 8(5): 4–6. **M**

Hiroi, J., T. Kaneko, and M. Tanaka. 1999. In vivo sequential changes in chloride cell morphology in the yolk-sac membrane of Mozambique tilapia (*Oreochromis mossambicus*) embryos and larvae during seawater adaptation. J. Exp. Biol. 202: 3485–3495. **M**

Hofkin, B. V., G. M. Mkogi, D. K. Koech, and E. S. Loker. 1991. Control of schistosome-transmitting snails in Kenya by the North American crayfish *Procambarus clarkii.* Amer. J. Trop. Med. Hyg. 45: 339–344. **M**

Hofkin, B. V., D. M. Hofinger, D. K. Koech, and E. S. Loker. 1992. Predation on *Biomphalaria* and

nontarget molluscs by the crayfish *Procambarus clarkii.* Ann. Trop. Med. Parasit. 86: 663–670. **M**

Hogg, N. D. 1973. Chlorinated Hydrocarbon Pesticide Residues, Salton Sea, California. MS thesis, Calif. State Polytechnic Univ. Pomona CA. 63 pp. **M**

Hogue, E. W. 1970. A comparative study of the osmoregulatory abilities of *Nereis succinea* from the Salton Sea and Alamitos Bay. Research report, Pomona College, Claremont CA. 14 pp. **M**

Holbert, M. B., ed. 1975. International Symposium on the Salinity of the Colorado River. Natural Resource J. 15: 1–239. **M**

Holbrook, G. F. 1928. Probable Future Stages of Salton Sea. US Geol. Surv. Open-file Rep. 34 pp.

Holden, P. B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River. pp. 57–74 in J. C. Ward and J. A. Stanford, eds. Ecology of Regulated Streams. Plenum Press, New York City NY. **M**

Holden, P. B., and C. B. Stalnaker. 1970. Systematic studies of the cyprinid genus *Gila* in the upper Colorado River basin. Copeia 1970: 409–420.

Holder, C. F. 1901a. A remarkable salt deposit, Salton, California. Sci. Amer. 84 (April): 217.

Holder, C. F. 1901b. Salton, California. National Geograph. Mag. 112: 391.

Holdren, G. C. 1998. Limnological assessment of the Salton Sea, Riverside and Imperial Counties, California. Prepared for Salton Sea Authority by US Bureau of Reclamation Ecological Research and Investigations Group, Denver CO. **M**

Holdren, G. C. 1999. Chemical and physical analyses of the Salton Sea, California. Prepared for the Salton Sea Authority by US Bureau of Reclamation Ecological Research and Investigations Group, Denver CO. **M**

Holdren, G. C., and A. Montaño. 2000. Chemical and physical limnology of the Salton Sea, Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract)

Holt, L. H. 1904. From Desert to Garden, from Worthlessness to Wealth: as Illustrated in the Imperial Settlement, San Diego County, Southern California. 6th ed., revised. Times-Mirror Printing and Binding House, Los Angeles CA. 37 pp.

Holt, L. H. 1907. The Unfriendly Attitude of the United States Government Towards the Imperial Valley. Imperial Daily Standard Printers, Imperial CA. 45 pp.

Hooper, L. 1920. The Cahuilla Indians. Univ. Calif. Publ. Amer. Archaeol. Ethnol. 16: 315–380.

Hoover, F. G. 1971. Status report on *Tilapia mossambica* (Peters) in southern California. Calif. Dept. Fish Game, Inland Fisheries Admin. Rep. 71–16. 31 pp. **M**

Hoover, F. G., and J. A. St. Amant. 1970. Establishment of *Tilapia mossambica* Peters in Bard Valley, Imperial County, California. Calif. Fish Game, 56: 70–71. **M**

Hopkins, V. 1985. The Colorado River. Chartwell Books, Secaucus NJ. 176 pp.

Hornbach, D. J. 1992. Life history traits of a riverine population of the Asian clam *Corbicula fluminea.* Amer. Midland Naturalist, 127: 248–257. **M**

Horvitz, S. 1995. Lost ships of the desert. Tracks (Colorado Desert District), November 1995: 1–2.

Horvitz, S. 2000. Salton Sea 101. Salton Sea Recreation Area. Center for Inland Waters, San Diego State University. ⟨www.sci.sdsu.edu/salton/SaltonSeaHomePage.html⟩ **M**

Hosmer, H. 1969. Triumph and failure in the Imperial Valley. Amer. West 3: 34–49. Reprinted as pp. 205–221 in T. H. Watkins, ed. The Grand Colorado: the Story of a River and its Canyon. American West, Palo Alto CA.

Hotos, G. N., and N. Vlahos. 1998. Salinity tolerance of *Mugil cephalus* and *Chelon labrosus* (Pisces: Mugilidae) fry in experimental conditions. Aquaculture, 167: 329–338. **M**

Howard, J. L. 1996. Paleocene to Holocene paleodeltas of ancestral Colorado River offset by the San Andreas fault system, southern California. Geology. 24: 783–790. **M**

Howe, E. F., and W. J. Hall. 1910. The Story of the First Decade in Imperial Valley, California. E. F. Howe and Sons, Imperial CA. 291 pp. **M**

Howells, R. G. 1990. Preliminary examination of low salinity tolerance of sperm, fertilized eggs, and larvae of the orangemouth corvina, *Cynoscion xanthulus.* Calif. Fish Game, 76: 58–62.

Hoyt, F. 1948. History of the Coachella Valley. MS thesis, Univ. Southern Calif., Los Angeles CA. Reprinted in part in Periscope (Coachella Hist. Soc., Indio CA) 1990: 11–41.

Hoyt, F. 1956. He discovered the dead sea of the Cahuillas. Desert Mag. 19 (July): 19–22.

Hubbs, C. L., and R. R. Miller. 1948. The Great Basin with evidence on glacial and postglacial times.

II. The zoological evidence: correlation between fish distribution and hydrographic history in the desert basins of western United States. Univ. Utah Bull. 38. 103–112.

Hughes, G. H. 1963. A Study of the Evaporation from the Salton Sea, California. US Geol. Surv. Open-file Rep. 63–51. 38 pp.

Hughes, G. H. 1967. Analysis of techniques used to measure evaporation from Salton Sea, California. US Geol. Surv. Prof. Pap. 272-H: 151–175.

Hughes, K. M., and P. Hughes. 1997. The conglomerate of Bear Canyon (Miocene). pp. 324–331 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Hughes, R. E. 1986. Trace element composition of Obsidian Butte, Imperial County, California. South. Calif. Acad. Sci. Bull. 85: 35–45.

Hulquist, R. G. 1981. A summary of Salton Sea creel censuses, 1958, 1963 through 1967, and 1969. Calif. Dept. Fish Game, Inland Fisheries, Region 5 Info. Bull. 0004–3–1981.

Hundley, N., Jr. 1986. The West against itself: the Colorado River—an institutional history. pp. 9–49 in G. D. Weatherford, and F. L. Brown, eds. New Courses for the Colorado River: Major Issues for the Next Century. Univ. New Mexico Press, Albuquerque NM. **M**

Hundley, N. J. 1992. The Great Thirst: Californians and Water, 1770s–1990s. Univ. Calif. Press, Berkeley CA. 551 pp.

Hune, J. V., and O. V. Lindqvist. 1995. Physiological adaptations of fresh-water crayfishes that permit successful aquacultural enterprises. Amer. Zool. 35: 12–19. **M**

Hunter, C. C. 1998a. Roadside geology of Imperial Valley. pp. 5–17 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. **M**

Hunter, C. C. 1998b. An investigation of the Hot Mineral Spa geothermal area, Riverside and Imperial Counties, California. pp. 93–108 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA.

Hunter, C. C., ed. 2000. The October 16, 1999 M_W 7.1 Hector Mine earthquake—initial response. Calif. Geol. 53 (1): 12–154. **M**

Hurlbert, A. ed. 1997. Wildlife Use of Agricultural Drains in the Imperial Valley, California. US Fish Wildlife Serv., Salton Sea National Wildlife Refuge. 98 pp.

Hurlbert, S. H. 1992, Salinity effects on the plankton and benthos of the Salton Sea. Univ. Calif. Riverside Water Resources Center. 6 pp.

Hurlbert, S. H. 2000. Overview of the little critters. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Hurlbert, S. H., D. Dexter, M. R. González, and C. M. Hart. 2000. Invertebrates recorded from the Salton Sea. Center for Inland Waters, San Diego State University CA ⟨www.sci.sdsu.edu/salton/SaltonSeaHomePage.html⟩ **M**

Hutchinson, G. E. 1975. A Treatise on Limnology. I. Geography, Physics and Chemistry. John Wiley, New York City NY. 1015 pp. **M**

Imperial County Agricultural Commission. 1990. 1990 Agricult. Crop Livestock Rep. 8 pp. **M**

Imperial County Planning and Building Department. 1994. West Shores/Salton City Urban Area Plan. Imperial County Planning Building Depart., El Centro CA. 43 pp.

Imperial Investment Company. 1912a. Listen!: To What we have to say about the Imperial Valley. Imperial Investment Company, Brawley CA. 10 pp.

Imperial Irrigation District. 1926. Boulder Dam, All-American Canal Project and Imperial Valley Pictorially. Imperial Irrigation District, Los Angeles CA. 40 pp.

Imperial Irrigation District. 1952. Water and Power, Imperial Irrigation District, Coachella Valley County Water District. Imperial Irrigation District, El Centro CA. 7 pp.

Imperial Irrigation District. 1960–1967. Folder of newspaper clippings and Imperial Irrigation District publications on the Salton Sea, soil salinity in Imperial and Coachella Valleys, power production and urban incroachment [*sic*] on agricultural lands. Imperial Irrigation District, El Centro CA. 13 items. in Univ. Calif. Berkeley library.

Imperial Irrigation District. 1986. Draft Environmental Impact Report on the Proposed Water Conservation Program and Initial Water Transfer. Calif. State Clearinghouse 86012903. Variously paginated.

Imperial Irrigation District. 1993. Results of desert pupfish trapping in Imperial Irrigation District drains, 8 August–21 September 1993. draft report. Imperial Irrigation District.

Imperial Irrigation District. 1994. Final Environmental Impact Report for Modified East Lowline and Trifolium Interceptors, and Completion Projects of the Water Conservation Program. Imperial Irrigation District. Variously paginated. **M**

Imperial Irrigation District Public Information Office. 1991. The All-American Canal. 5 pp. **M**

Imperial Irrigation District Public Information Office. 1998a. Imperial Irrigation District. 1 p **M.**

Imperial Irrigation District Public Information Office. 1998b. Salton Sea. 4 pp. **M**

Imperial Irrigation District Public Information Office. 1998c. Aquatic weed control. 4 p. **M**

Imperial Land Company. 1902. An Album of Imperial Settlements, San Diego County, California, Illustrating the Largest and Finest Irrigation System Now Working for the Conquest of Arid California. Times Mirror Printing and Binding House, Los Angeles CA. 48 pp.

Imperial Land Company. 1904. Imperial Valley Catechism. 12th ed. revised. Imperial Land Co., Los Angeles CA. 24 pp.

Irelan, B. 1971. Salinity of surface water in the lower Colorado River-Salton Sea area. US Geol. Surv. Prof. Pap. 486-E. 40 pp.

Irwin, G. A. 1971. Water-quality Data for Selected Sites Tributary to the Salton Sea, California, August 1969–June 1970. US Geol. Surv. Open-file Report 7414–10. 12 pp. **M**

Irwin, W. P. 1990. Geology and plate-tectonic development. The San Andreas Fault System, California. US Geol. Surv. Prof. Pap. 1515: 61–80. **M**

Isaacs, J. D. 1972. Unstructure of marine food webs and "pollutant analogues." Fish. Bull. 70: 1053–1059. **M**

Isaacs, J. D. 1973. Potential trophic biomasses and trace-substance concentrations in unstructured marine food webs. Mar. Biol. 22: 97–104. **M**

Ismail, N. S., and A. M. S. Arif. 1993. Population dynamics of *Melanoides tuberculata* (Thiaridae) snails in a desert spring, United Arab Emirates, and infection with larval trematodes. Hydrobiologia, 257: 57–64. **M**

Ives, R. L. 1951. Mud volcanoes of the Salton depression. Rocks Minerals, 26: 227–235.

Jackson, J. 1988. Surveys for the Yuma clapper rail and the California black rail along the 38-mile unlined portion of the Coachella Canal and adjacent wetlands, Imperial and Riverside Counties. Calif. Admin. Rep., U.S. Bur. Reclam., Boulder City NV.

Jacob, J. 1957. Cytological studies of Melaniidae (Mollusca) with special reference to parthenogenesis and polyploidy. I. Oögenesis of the parthenogenetic species of *Melanoides* (Prosobranchia: Gastropoda). Roy. Soc. Edinb. Trans. 63: 341–352. **M**

Jacob, J. 1958. Cytological studies of Melaniidae (Mollusca) with special reference to parthenogenesis and polyploidy. II. A study of meiosis in the rare males of the polyploid race of *Melanoides tuberculatus* and *Melanoides lineatus*. Roy. Soc. Edinb. Trans. 63: 433–444. **M**

Jahns, R. H., ed. 1954. Geology of Southern California. Geol. Soc. Amer. Bull. 170. 3 vols.

James, G. W. 1906. The overflow of the Colorado and the Salton Sea—II. Sci. Amer. 21 April 1906: 328–329.

James, G. W. 1907. The Wonders of the Colorado Desert (Southern California), its Rivers and Mountains, its Canyons and its Springs, its Life and its History, Pictured and Described, including an Account of a Recent Journey made down to the Overflow of the Colorado River to the Mysterious Salton Sea. Little, Brown and Co., Boston. 2 vols. 547 pp. **M**

James, H. C. 1960. The Cahuilla Indians. Malki Museum Press, Morongo Indian Reservation. Westernlore Press. 185 pp. **M**

Jang, E. B., and R. E. Tullis. 1980. Hydromineral regulation in the saline water corixid *Trichocorixa reticulata* (Hemiptera: Corixidae). J. Insect Physiol. 26: 241–244.

Jansen, M., N. Philips, J. M. "Tex" Ritter, and R. Williams. 1985. How to Fish the Salton Sea. Triumph Press, Los Angeles CA. 128 pp. **M**

Jarne, P., and B. Delay. 1991. Population genetics of freshwater snails. Trends Ecol. Evol. 6: 383–386. **M**

Jarne, P., and T. Stadler. 1995. Population genetic-structure and mating system evolution in fresh-water pulmonates. Experientia, 51: 482–494. **M**

Jefferson, G. T., and D. G. Peterson, Jr. 1998. Hydrothermal origin of the Fish Creek gypsum. pp. 40–51 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA.

Jefferson, G. T., and P. Remeika. 1995. The mid-Pleistocene stratigraphic co-occurrence of *Mammuthus columbi* and *M. imperator* in the Ocotillo Formation, Borrego Badlands, Anza-Borrego Desert State Park, California. pp. 104–108 in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol., San Diego CA.

Jehl, J. R., Jr. 1988. Biology of eared grebes and Wilson's phalarope in the nonbreeding season: a study of adaptations to saline lakes. Studies in Avian Biology, 12: 1–74. (abstract)

Jehl, J. R., Jr. 1993. Observations of the fall migration of eared grebes, based on evidence from a mass drowning in Utah. Condor, 95: 470–473. (abstract)

Jehl, J. R., Jr. 1994. Changes in saline and alkaline lake avifaunas in western North America in the past 150 years. Studies Avian Biol. 15: 258–272. (abstract)

Jehl, J. R., Jr. 1996. Mass mortality events of eared grebes in North America. J. Field Ornithol. 67: 471–476. **M**

Jehl, J. R., Jr. 1997. Cyclical changes in body composition in the annual cycle and migration of the eared grebe *Podiceps nigricollis*. J. Avian Biol. 28: 132–142. **M**

Jehl, J. R., Jr. 2000. The migration of eared grebes through the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Jehl, J. R., Jr., and S. I. Bond. 1983. Mortality of eared grebes in winter of 1982–83. Amer. Birds, 37: 832–835. (abstract)

Jehl, J. R., and P. K. Yochem. 1986. Movements of eared grebes indicated by banding recoveries. J. Field Ornithol. 57: 208–212.

Jennings, M. R. 1983. An annotated checklist of the amphibians and reptiles of California. Calif. Fish Game, 69: 151–171.

Jet Propulsion Laboratory. 1980. The Salton Sea Solar Pond Project. Calif. Inst. Technol. Jet Propul. Lab. NAS 1.12/7:400–70. 13 pp.

John Corollo Engineers. 1974. Desert Shores, Salton Sea Beach: Environmental Assessment. Salton Community Ser. Dist., Santa Ana CA. Variously paginated.

Johnson, H. 1925. The Epic of the Imperial Valley. An address delivered before the Commonwealth Club of San Francisco on October 17, 1925 and the Public Spirit Club of Oakland, on October 20, 1925.

Johnson, H. O., D. C. Agnew, and F. K. Wyatt. 1994. Present-day crustal deformation in southern California. J. Geophys. Res.-Solid Earth, 99: 23951–23974. **M**

Johnson, M. W. 1953. The copepod *Cyclops dimorphus* Kiefer from the Salton Sea. Amer. Midland Naturalist, 49: 188–192. **M**

Johnson, P. B., and M. A. Adams. 1986. Chemical feeding stimulants for the herbivorous fish *Tilapia zillii*. Comp. Biochem. Physiol. 83: 109–112.

Johnston, F. J. 1987. The Bradshaw Trail. Revised ed. Historical Commission Press, Riverside CA. 229 pp. **M**

Jones, J. C. 1914. The tufa deposits of the Salton Sea. pp. 79–84 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L. **M**

Jurek, R. M. 1975. Survey of Yuma clapper rails and California black rails along the Coachella Canal, Imperial County, May 1975. Calif. Dept. Fish Game, Nongame Wildlife Invest. 6 pp.

Jurgens, K., and E. Jeppesen. 2000. The impact of metazooplankton on the structure of the microbial food web in a shallow, hypertrophic lake. J. Plank. Res. 22: 1047–1070. **M**

Kaddah, M. T., and J. D. Rhoads. 1976. Salt and water balance in Imperial Valley, California. Soil Sci. Soc. Amer. J. 40: 93–100.

Kahrl, W. L., ed. 1978. California Water Atlas. William Kaufman, Los Angeles CA. 118 pp. **M**

Kahrl, W. L. 1982. Water and Power: The Conflict over Los Angeles' Water Supply in the Owens Valley. Univ. Calif. Press, Berkeley CA. 583 pp. **M**

Kaiser, J. 1999. Battle over a dying sea. Science 284: 28–30. **M**

Kaiser, J. 2000. Bringing the Salton Sea back to life. Science 287: 565. **M**

Karr, B. 1985. Fishing the Salton Sea, "The Best Fishing in California." Desert Printing Co., Indio CA. 51 pp. **M**

Kaufman, K. 1977. The changing seasons: an intimate look at *Kathleen* and other avian phenomena of autumn 1976. Amer. Birds, 31: 142–152. **M**

KEA Environmental. 1997. Archaeological Survey and Evaluation Program for the Salton Sea Test Base, Imperial County, California. Report prepared for Depart. Navy Southwestern Div. San Diego CA.

Kelley, R. C., and J. L. Soske. 1936. Origin of the Salton volcanic domes, Salton Sea, California. J. Geol. 44: 496–509. **M**

Kelly, A., E. 1913. Imperial Valley: the Nile Valley of America. A Half Million Acres of the Colorado Desert Reclaimed. Imperial Valley Board of Supervisors and Imperial Valley Chamber of Commerce, El Centro Ca. 16 pp.

Kelly, W. H. 1977. Cocopa Ethnography. Univ. Arizona Archaeol. Pap. #29.

Kennan, G. 1917. The Salton Sea: an Account of Harriman's Fight with the Colorado River. Macmillàn, New York City. 106 pp. **M**

Kennedy, C. H. 1916. A possible enemy of the mosquito. Calif. Fish Game, 2: 179–182. **M**

Kerlinger, P. 1995, The economic impact of birding ecotourism on the Salton Sea National Wildlife Refuge area, California, 1993–1994. Environmental Consulting & New Jersey Audubon Society, Cape May NJ.

Kiefer, F. 1934. Neue Ruderfusskrebse aus Nordamerika. Zool. Anz. 107: 269–271. **M**

Kim, G. M., M. O. Zeldin, and C. S. Liu. 1992. Source apportionment study for state implementation plan development in the Coachella Valley. in J. C. Chow and D. M. Ono, eds. PM-10 Standards and Nontraditional Particulate Source Controls. Vol. 22. Air Waste Manag. Assoc. Trans.

Kim, J. 1973. Ecosystem of the Salton Sea. pp. 601–605 in W. C. Ackermann, G. F. White, and E. B. Worthington, eds. Man-Made Lakes: Their Problems and Environmental Effects. Amer. Geophys. Union, Geol. Monogr. 17. **M**

Kim, J., and M. K. Nakaji. 1969. Microbial ecology of the Salton Sea. Bacteriol. Proc. 1969: 35 (abstract).

King, C. 1988. Shell beads from CA-RIV-1179. in Archaeological Investigations at CA-RIV-1179, CA-RIV-2823, and CA-RIV-2827, La Quinta, Riverside County, California. Coyote Press Archiv. Calif. Prehistory, #20. Salinas CA.

King, C. E., and M. Serra. 1998. Seasonal variation as a determinant of population structure in rotifers reproducing by cyclical parthenogenesis. Hydrobiologia, 387: 361–372. **M**

Kinne, O. 1960. Growth, food intake, and food conversion in a euryplastic fish exposed to different temperatures and salinities. Physiol. Zool. 33: 288–317. **M**

Kinne, O. 1965. Salinity requirements of the fish, *Cyprinodon macularius.* US Pub. Health Serv. Publ. 999-WP-25: 187–192.

Kinne, O. 1971. 4. Salinity. 4.3. Animals. 4.3.1. Invertebrates. pp. 821–995 in O. Kinne, ed. Marine Ecology. Vol. 1. Environmental factors. Wiley, New York City NY. **M**

Kinne, O., and E. M. Kinne. 1962. Rates of development in embryos of a cyprinodont fish exposed to different temperature-salinity-oxygen combinations. Canad. J. Zool. 40: 231–253. **M**

Kishel, J. 1993. Lining the All-American Canal: legal problems and physical solutions. Natural Resources J. 33: 697–726.

Klym, J. C. 1997. The Salton Sea: from problems to economic asset, a plan to decrease salinity. Calif. County September/October 1977: 313–32.

Knaak, M. 1981. Ethnography. pp. 55–82 in E. von T. Warren, R. H. Crabtree, C. N. Warren, M. Knack, and R. McCarty, eds. A Cultural Resources Overview of the Colorado Desert Planning Units. Cult. Resources Publ. Anthropol.-Hist. US Bureau Land Manag. Calif. Desert Dist. Riverside CA.

Knaak, M. 1988. The Forgotten Artist: Indians of Anza-Borrego and their Rock Art. Anza-Borrego Desert Natural Hist. Assoc. Calif. 117 pp.

Knaggs, E. H. 1976. Status of the genus *Tilapia* in California's estuarine and marine waters. Or, get your (expletive deleted) exotic freshwater fish out of my ocean. Calif. Dept. Fish Game Operations Res. Branch. MS. 7 pp.

Knaggs, E. H. 1977. Status of the genus *Tilapia* in California's estuarine and marine waters. Cal-Neva Wildlife Trans. 1977: 60–67. **M**

Kniffen, F. B. 1931. The primitive cultural landscape of the Colorado Delta. Univ. Calif. Publ. Geol. 5: 43–66. **M**

Kniffen, F. B. 1932. The natural landscape of the Colorado Delta. Lower Colorado Studies IV. Univ. Calif. Publ. Geog., 5: 149–244.

Knopf, F. L. 1998. Foods of mountain plovers wintering in California. Condor, 100: 382–384.

Knopf, F. L., and J. R. Rupert. 1995. Habits and habitats of mountain plovers in California. Condor, 97: 743–751.

Koenig, J. B. 1967. The Salton-Mexicali geothermal province. Calif. Div. Mines Geol. Mineral Inform. Serv. 20: 75–81.

Koerper, H. L., J. E. Ericson, C. E. Denver, and P. E. Langenwalter II. 1986. Obsidian exchanged in prehistoric Orange County. Pacific Coast. Archaeol. Soc. Quart. 22: 33–69. **M**

Kohler-Antablin, S. 1999. California non-fuel minerals— 1998. Calif. Geol. 52 (5): 17–20. **M**

Koranda, J. J., M. Stuart, S. Thompson, and C. Conrad. 1979. Biogeochemical studies of wintering waterfowl in the Imperial and Sacramento Valleys. Lawrence Livermore National Lab, Univ. Calif. Rep. UCID-18288.

Kotrla, M. B. 1975. New geographic location for *Philophthalmus* sp. in thiarid snails and waterfowl in Texas. Amer. Malacol. Union Bull. 1975: 41–42. **M**

Kotrla, M. B. 1977. Histological and ultrastructural studies of *Tarebia granifera* (Gastropoda) hepatopancreas parasitized by *Philophthalmus gralli* (Trematoda). Amer. Malacol. Union Bull. 43: 89–90. **M**

Kotrla, M. B. 1983. Morphology of *Tarebia granifera* (Gastropoda: Thiaridae) digestive gland infected with *Philophthalmus gralli* (Trematoda: Philophthalmidae) rediae. Amer. Zool. 23(4): 905. **M**

Kotrla, M. B., and H. D. Murray. 1980. Correlations of shell measurements, sex, and trematode infection in *Tarebia granifera* in Texas. Amer. Malacol. Union Bull. 46: 70. **M**

Kovach, R. L., C. A. Allen, and F. Press. 1962. Geophysical investigation in the Colorado Delta region. J. Geophys. Res. 67: 2845–2871.

Kowalewski, M, G. E. A. Serrano, K. W. Flessa, and G. A. Goodfriend. 2000. Dead delta's former productivity: two trillion shells at the mouth of the Colorado River. Geology, 28: 1059–1062. (abstract) **M**

Krantz, T. P., and M. Ward. 2000. Vegetation mapping of the Salton Sea basin. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract)

Krantz, T. P., S. Yoshihara, and D. Chambers. 2000. Christmas bird counts at the Salton Sea: presenting 30 years of wintering bird data. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract)

Kroeber, A. L. 1908. Ethnography of the Cahuilla. Univ. Calif. Publ. Amer. Archaeol. Ethanol. 8 (2): 29–68. **M**

Kroeber, A. L. 1925. Handbook of the Indians of California. Smithsonian Inst. Bur. Amer. Ethnol. Bull 76. Reprint 1976 Dover Publ. New York City NY. 995 pp. **M**

Kudenov, J. D. 1983. The first record of *Boccardia ligerica* (Polychaeta: Spionidae) from Imperial County, California. South. Calif. Acad. Sci. Bull. 82: 144–146. **M**

Kuhl, D., and L. C. Oglesby. 1979. Reproduction and survival of the pileworm *Nereis succinea* in higher Salton Sea salinities. Biol. Bull. 157: 153–165. **M**

Kültz, D., and H. Onken. 1993. Long-term acclimation of the teleost *Oreochromis mossambicus* to various salinities: two different strategies in mastering hypertonic stress. Mar. Biol. 117: 527–533. **M**

Kuperman, B. I., and V. E. Matey. 1999. Massive infestation by *Amyloödinium ocellatum* (Dinoflagellida) of fish in a highly saline lake, Salton Sea, California, USA. Diseases Aquat. Organisms, 39: 65–73. **M**

Kuperman, B. I., and V. E. Matey. 2000. Ectoparasites of fish and invertebrates of the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. modified version: Center for Inland Waters, San Diego State University, CA. ⟨www.sci.sdsu.edu/salton/SaltonSeaHomePage.html⟩ **M**

Kuperman, B. I., V. E. Matey, D. M. Dexter, and M. A. Tiffany. 2000. Invertebrates of the Salton Sea: a scanning electron microscope portfolio. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. modified version: Center for Inland Waters, San Diego State University, CA. ⟨www.sci.sdsu.edu/salton/SaltonSeaHomePage.html⟩ **M**

Laamrani, H., K. Khallayoune, B. Delay, and J.-P. Pointier. 1997. Factors affecting the distribution and abundance of two prosobranch snails in a thermal spring. J. Freshwater Ecol. 12: 75–79.

Lachebruch, A. H., J. H. Sass, and J. H. Galanis, Jr. 1985. Heat flow in southernmost California and the origin of the Salton Trough. J. Geophys. Res. 90: 6709–6736.

Laflin, P. B. 1995. Salton Sea: California's Overlooked Treasure. Periscope (Coachella Valley Hist. Soc.). 56 pp. **M**

Laflin, P. B. 1998. Coachella Valley, California: a Pictorial History. Donning Co. Publ., Virginia Beach VA. 192 pp. **M**

LaFrance, K., and E. Ruben. 1985. The life cycle and productivity of the amphipod *Gammarus mucronatus* in a northern Massachusetts salt marsh. Limnol. Oceanogr. 30: 1067–1077. **M**

Lande, D. 1979. A history of geothermal drilling in the Imperial Valley. pp. 45–46 in W. A. Elders, ed. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Mus. Contrib. 5. **M**

Landis, C. 2000. In Search of Eldorado: the Salton Sea. Palm Springs Desert Museum, Palm Springs CA. 48 pp. **M**

Lange, C. B., and M. A. Tiffany. 2000. The diatom flora of the Salton Sea, California. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (modified version) Center for Inland Waters, San Diego State University, CA. ⟨www.sci.sdsu.edu/salton/SaltonSeaHomePage.html⟩**M**

Lange, G. D., and A. C. Hurley. 1975. A theoretical treatment of unstructured food webs. Fish. Bull. 57: 378–381. **M**

Larsen, S., and R. Reilinger. 1991. Age constraints for the present fault configuration in the Imperial Valley, California—evidence for northwestward propagation of the Gulf of California rift system. J. Geophys. Res.-Solid Earth, 96: 10339–10346. **M**

Larson, R. I., H. W. Menard, and S. M. Smith. 1968. Gulf of California: a result of ocean-floor spreading and transform faulting. Science 161: 761–764.

Lasker, R., R. H. Tenaza, and L. L. Chamberlain. 1972. The response of Salton Sea fish eggs and larvae to salinity stress. Calif. Fish Game, 58: 58–66. **M**

Lattin, O. 1986. Age and growth of *Bairdiella icistia* in the Salton Sea using scales and otoliths. MS thesis, Calif. State Univ. Long Beach.

Latting, J., and P. G. Rowlands, eds. 1995. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA. 665 pp.

Lau, S., and C. Boehm. 1991. A distribution survey of desert pupfish (*Cyprinodon macularius*) around the Salton Sea, California. Final Report for Section 6, Project EF90XII–1. Prepared for Calif. Dept. Fish Game, Inland Fish. Div. 21 pp. (abstract) **M**

Lau, S., M. Mohammed, A. T. C. Yen, and S. Su'ut. 1998. Accumulation of heavy metals in freshwater molluscs. Sci. Total Environ. 214:113–121.

Lauff, G. H. 1967. Estuaries. Amer. Assoc. Adv. Sci., Washington DC Publ. 83. 757 pp.

Lawton, H. W. 1976. An ethnographic history of the Yuha Desert. pp. 43–72 in P. Wilke, ed. Background to Prehistory of the Yuha Desert Region. Ballena Press Anthropol. Pap. 5. Ballena Press, Ramona CA.

Lawton, H. W., and L. J. Bean. 1968. A preliminary reconstruction of aboriginal agricultural technology among the Cahuilla. Indian Historian, 1(5): 18–24, 29.

Laylander, D. 1978. Some linguistic approaches to southern California prehistory. Cultural Resource Manag. Center, Cultural Resources Center Casual Pap. 2: 14–59.

Laylander, D. 1993. Historic Property Survey-Negative Findings: Report for Widening of bridges #58–0124 and #57–0096. Report on file with Caltrans District 11, San Diego CA.

Laylander, D. 1994. Phase III Data Recovery at the Elmore Site (CA-IMP-6427), Imperial County, California. Caltrans, District 11, San Diego.

Laylander, D. 1995. The chronology of Lake Cahuilla's final stand. Soc. Calif. Archaeol. Proc. 8: 69–78.

Laylander, D. 1997. The last days of Lake Cahuilla: the Elmore Site. Pacific Coast Archaeol. Soc. Quart. 33 (1–2): 1–138.

Layton, D. W. 1978a. Water for long-term geothermal energy production in the Imperial Valley. Univ. Calif. Lawrence Livermore National Laboratory, UCRL-52576: 1–48. **M**

Layton, D. W. 1978b. Water supply dilemmas of geothermal development in the Imperial Valley of California. Water Resource Bull. 14: 133–143. **M**

Layton, D. W., and D. Ermak. 1976. A description of Imperial Valley, California, for the assessment

of impacts of geothermal energy development. Lawrence Livermore National Laboratory, Univ. Calif. Livermore Category Distrib. UC-66. **M**

Lebo, A., L. Nitikman, and C. Salmen. 1982. San Sebastian Marsh: a Resource Survey and Management Plan, Imperial County, California. Environmental Field Program, Univ. Calif. Santa Cruz. Publ. #9. 333 pp. **M**

Lebo, M. E., J. E. Reuter, C. R. Goldman, and C. L. Rhodes. 1994. Interannual variability of nitrogen limitation in a desert lake—influence of regional climate. Canad. J. Fish. Aquat. Sci. 51: 862–872. **M**

LeConte, J. L. 1855. An account of some volcanic springs in the desert of the Colorado, California. Amer. J. Sci. 19: 1–6.

Legner, E., and T. Fisher. 1980. Impact of *Tilapia zillii* (Gervais) on *Potamogeton pectinatus* L., *Myriophyllum spicatum* var. *exalbescens* Jepson, and mosquito reproduction in lower Colorado Desert irrigation canals. Acta Oecol. Applicata, 1: 3–14.

Legner, E., and F. Pelsue. 1977. Adaptations of *Tilapia* to *Culex* and chironomid midge ecosystems in Southern California. Proc. Ann. Conf. Mosquito Vector Control Assoc. 45: 95–97.

Leitner, P. and G. S. Grant. 1978. Observations on water bird flight patterns at Salton Sea, California, October 1976–February 1977. Univ. Calif. Lawrence Livermore National Lab, UCRL-13818. **M**

Leopold, A. 1949. A Sand County Almanac and Sketches Here and There. Oxford Univ. Press, New York City NY. 226 pp. **M**

Levenkron, D. J. 1982. Sand and Rubble: the Salton City Story. Justice Publ. Los Angeles. 319 pp.

Levin, L. A., and T. S. Bridges. 1994. Control and consequences of alternative developmental modes in a poecilogonous polychaete. Amer. Zool. 34: 323–332. **M**

Levin, L. A., J. Zhu, and E. Creed. 1991. The genetic basis of life history characters in a polychaete exhibiting planktotrophy and lecithotrophy. Evolution, 45: 380–397. **M**

LFR. 1999. Synthesis document of current information on the sediment physical characteristics and contaminants of the Salton Sea, Riverside and Imperial Counties, California. Prepared by LFR Levine-Fricke for Salton Sea Authority. Salton Sea Database Program, U. of Redlands, CA. ⟨www.institute.redlands.edu/Salton/recon/index.aspx⟩ **M**

Liao, M. 1996. RAPD Analysis of Genetic Variability in the Freshwater Snails *Thiara granifera* and *Thiara tuberculata.* Senior thesis, Pomona College, Claremont CA. 33 pp. **M**

Lindsay, D. 2001. Anza-Borrego from A to Z: People, Places, and Things. Sunbelt Publ., San Diego CA. 400 pp. **M**

Lindsay, L., and W. G. Hample, eds. 1998. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. 187 pp. **M**

Linsley, R. H., and L. H. Carpelan. 1961. Invertebrate fauna [of the Salton Sea]. Calif. Dept. Fish Game, Fish Bull. 113: 43–47. **M**

Lipovsky, S. J., and C. A. Simenstad, eds. Gutshop '78. Fish Food Habits Studies. Proc. 2nd. Pacific Northwest Tech. Workshop. Washington Sea Grant Publ. WSG-WO-79-1. 222 pp.

Lippincott, J. B. 1902–1908. Colorado Delta Canal Company. 2 items in Univ. Calif. library.

Little, J. B. 2000. Mono Lake rising: adding water is just the first step in the recipe for renewal. Calif. Wild, 53(3): 14–19. **M**

Littlefield, W. M. 1966. Hydrology and physiography of the Salton Sea, California. US Geol. Surv. Hydrol. Invest. Atlas HA-222.

Llansó, R. J. 1991. Tolerance of low dissolved oxygen and hydrogen sulfide by the polychaete *Streblospio benedicti.* J. Exp. Mar. Biol. Ecol. 153: 165–178.

Loch, J. J., and S. A. Bonar. 1999. Occurrence of grass carp in the lower Columbia and Snake rivers. Amer. Fish. Soc. Trans. 128: 374–379. **M**

Loeltz, O. J. 1979. Relation between Proposed Developments of Water Resources and Seepage from the All-American Canal, Eastern Imperial Valley. US Geol. Surv. Open-file Rep. 83 pp.

Loeltz, O. J., B. Irelan, J. H. Robison, and F. H. Olmstead. 1975. Geohydrologic reconnaissance of the Imperial Valley, California. US Geol. Surv. Prof. Pap. 486-K. 54 pp.

Lofgren, B. E. 1978a. Salton Trough continues to deepen in Imperial Valley, California. Amer. Geophys. Union, Trans. 59: 1051.

Lofgren, B. E. 1978b. Measured crustal deformation in Imperial Valley. US Geol. Surv. Open-file Rep. 78–910. 4 pp.

Lofgren, B. E. 1979a. Measured crustal deformation in Imperial Valley, California. Geothermics, 8: 267–272.

Lofgren, B. E. 1979b. Monitoring crustal deformation in the Imperial Valley-Mexicali Valley structural trough. p. 47 in W. A. Elders, ed.'Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Mus. Contrib. 5. **M**

Lofgren, B. E. 1979c. Measured crustal deformation in Imperial Valley, California. pp. 48–52 in W. A. Elders, ed. Geology and Geothermics of the Salton Trough. Univ. Calif. Riverside Mus. Contrib. 5.

Longwell, C. R. 1954. History of the Lower Colorado River and the Imperial Depression, California. Calif. Bur. Mines Bull. 170: 53–56.

Lonzarich, D. G., and J. J. Smith. 1997. Water chemistry and community structure of saline and hypersaline salt evaporation ponds in San Francisco Bay, California. Calif. Fish Game, 83: 89–104.

Lopez, A. 1998. Testimony of Arthur Lopez, Chairman of The Torres-Martínez Desert Band of Cahuilla Indians before the United States House of Representatives Committee on Resources Subcommittee on Water and Power Concerning H. R. 3267, "Sonny Bono Memorial Salton Sea Reclamation Act," 12 March 1998. Washington DC. **M**

Loretz, C. A. 1979. Osmotic and cell volume regulation in the goby, *Gillichthys mirabilis.* J. Exp. Zool. 210: 237–244. **M**

Losi, M. E., and W. T. Frankenberger, Jr. 1997. Bioremediation of selenium in soil and water. Soil Sci. 162: 692–702. **M**

Lothrop, B. B., and M. Mulla. 1995. Mode of existence and seasonality of midge larvae (Diptera, Chironomidae) in man-made lakes in the Coachella Valley, southern California. J. Amer. Mosq. Control Assoc. 11: 77–85. **M**

Lough, C. F. 1993. Structure and evolution of the Vallecito Mountains. pp. 91–109 in J. Corones, ed. Colorado Desert and Salton Trough Geology. San Diego Assoc. Geol. Annual Field Trip Guide. San Diego CA.

Lough, C. F. 1998. Detachment faulting around Borrego Valley. pp. 52–58 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. **M**

Loumala, K. 1978. Tipai and Ipai. pp. 92–609 in: R. F. Heizer, ed. Handbook of the Indians of North America. Smithsonian Inst. Washington DC.

Love, B. 1996. Archaeology on the North Shoreline of Ancient Lake Cahuilla. Prepared by CRM TECH, Riverside CA, for US Home Corp. Tempe AZ.

Lowe, B. T., and A. J. Provenzano. 1990. Survival and reproduction of *Palaemonetes paludosus* (Gibbes, 1850) (Decapoda: Palaemonidae) in saline water. J. Crust. Biol. 10: 639–647.

Lowe, C. H., and W. G. Heath. 1969. Behavioral and physiological responses to temperature in the desert pupfish *Cyprinodon macularius.* Physiol. Zool. 42: 53–59.

Lubzens, E., G. Minkoff, and S. Marom. 1985. Salinity dependence of sexual and asexual reproduction in the rotifer *Brachionus plicatilis.* Mar. Biol. 85: 123–126. **M**

Lubzens, E., G. Minkoff, Y. Barr, and O. Zamora. 1997. Mariculture in Israel—past achievements and future directions in raising rotifers as food for marine fish larvae. Hydrobiologia, 358: 13–20. **M**

Lucas, F., and G. Bertru. 1997. Bacteriolysis in the gut of *Nereis diversicolor* (O. F. Müller) and effect of the diet. J. Exp. Mar. Biol. Ecol. 215: 235–245. **M**

Lucchitta, I. 1972. Early history of the Colorado River in the Basin and Range Province. Geol. Soc. Amer. Bull. 83: 11933–1948.

Lucchitta, I. 1979. Late Cenozoic uplift of the southwestern Colorado Plateau and adjacent lower Colorado River region. Tectonophysics, 61: 63–95.

Lucchitta, I. 1990. History of the Grand Canyon and of the Colorado River in Arizona. pp. 311–332 in S. S. Beus and M. Morales, eds. Grand Canyon Geology. Oxford Univ. Press, New York City. **M**

Lujan, M. N. 1989. Report to Congress on Salton Sea National Wildlife Refuge. US Dept. Interior. 14 December 1989.

Luomala, K. 1963. Flexibility in sib affiliation among the Diegueño. Ethnology, 2: 282–301.

Luomala, K. 1978. Tipai and Ipai. pp. 592–609 in R. F. Heizer, ed. Handbook of North American Indians, Vol. 8, California. Smithsonian Inst. Press, Washington DC.

Luten, D. B. 1967. The use and misuse of a river. Amer. West, 4(2): 47–53, 73–75.

MacDougal, D. T. 1907. The desert basins of the Colorado Delta. Amer. Geograph. Soc. Bull. 25 pp.

MacDougal, D. T. 1908. A voyage below sea level on the Salton Sea. Outing, 1908: 592–601.

MacDougal, D. T., ed. 1914a. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L: 182 pp. **M**

MacDougal, D. T. 1914b. Movements of vegetation due to submersion and desiccation of land areas in the Salton Sink. pp. 115–172 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin Carnegie Inst. Washington Publ. 193L. **M**

MacDougal, D. T. 1914c. General discussion [of the newly formed Salton Sea]. pp. 173–182 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L.

MacDougal, D. T. 1915. The Salton Sea. Amer. J. Sci. 39: 231–250.

MacDougal, D. T. 1916. The recession of the Salton Sea. Carnegie Inst. Washington Yearbook, 14: 90.

MacDougal, D. T. 1917. A decade of the Salton Sea. Geograph. Rev. 3: 457–473.

MacDougal, D. T., and G. Sykes. 1915. The travertine record of Blake Sea. Science 42: 113–134. **M**

Madhavi, R., K. Umadevi, and V. G. M Sarnmakumari. 1997. Community structure of larval trematode fauna of the snail *Thiara tuberculata* from a freshwater stream at Visakhapatnam, Andhra Pradesh. Current Sci. 72: 582–585. **M**

Maimoni, A. 1982. Minerals recovery from the Salton Sea geothermal brines: a literature review and proposed cementation process. Geothermics, 11: 239–258.

Maloney, N. J. 1986. Coastal landforms of Holocene Lake Cahuilla, northeastern Salton Basin, California. pp. 151–158 in P. G. Guptill, R. W. Ruff, and E. M. Grath, eds. Geology of the Imperial Valley, California. South Coast Geol. Soc. Guidebook #14, Santa Ana CA. **M**

Marsh, P. C. 1985. Effect of incubation temperature on survival of embryos of native Colorado river fishes. Southwestern Naturalist, 30: 129–140.

Marsh, P. C. 1987. Digestive tract contents of adult razorback suckers in Lake Mohave, Arizona-Nevada. Amer. Fish. Soc. Trans. 116: 117–119.

Marsh, P. C., and C. R. Stinemetz. 1983. Benthic invertebrates of the earthen Coachella Canal, California. Calif. Fish Game, 69: 77–83. **M**

Mason, C. 1981. Imperial Valley to the World: an Adventure in American Free Enterprise. Imperial Oil Grease Co., Los Angeles. 196 pp.

Mason, H. L. 1957. A Flora of the Marshes of California. Univ. Calif. Press, Berkeley CA. 878 pp. **M**

Martínez Zepeda, J., and L. Romero Navarrette, eds. 1991. Mexicali: una Historia. Universidad Autónoma de Baja California, Instituto Investigaciónes Historicas, Mexicali, Baja California, México. 2 vols.

Mathias, M. E. 1995. University of California Natural Reserve System. pp. 397–403 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Matsui, M. 1981. The Effects of Introduced Teleost Species on Social Behavior of *Cyprinodon macularius californiensis.* MS thesis, Occidental College, Los Angeles CA. 61 pp.

Matsui, M. L., A. B. Bond, G. Jordan, R. Moore, P. Garrahan, K. Iwanaga, and S. Williams. 1991a. Abundance and distribution of the ichthyoplankton in the Salton Sea, California, in relation to water quality. Final Performance Report, Federal Aid Project F-51-R, Study #3, Subproject VI: Salton Sea Sport Fish Research. Calif. Dept. Fish Game, Sacramento CA. 40 pp. (abstract) **M**

Matsui, M., G. L. Lattin, R. Moore, C. Mulski, and A. B. Bond. 1991b. Salinity tolerance of *Anisotremus davidsoni.* Final Report, Federal Project F-51-R, Study #2. Calif. Dept. Fish Game. (abstract) **M**

Matsui, M., G. L. Lattin, R. Moore, C. Mulski, and A. B. Bond. 1991c. Salinity tolerance of *Cynoscion xanthulus.* Final Report, Federal Project F-51-R, Study #2. Calif. Dept. Fish Game. (abstract) **M**

Matsui, M., J. E. Hose, P. Garrahan, and G. A. Jordan. 1992. Developmental defects in fish embryos from Salton Sea, California. Bull. Environ. Contam. Toxicol. 48: 914–920. **M**

Matthews, N. 1982. The old woman and the sea. Fishermen, farmers, oil companies—all have designs on the Salton Sea. So does Helen Burns, whose marina is now beneath its waters. Calif. Mag. March 1982: 84–90, 158–161. **M**

Matti, J. C., and D. M. Morton. 1993. Paleogeographic evolution of the San Andreas Fault in southern

California: a reconstruction based on a new cross-fault correlation. pp. 107–160 in R. E. Powell, R. J. Weldon, and J. C. Matti, eds. The San Andreas Fault System: Displacement, Palinspastic Reconstruction and Geologic Evolution. Geol. Soc. Amer. Mem. 178.

Maxwell, W. D. 1975. The croakers of California. Calif. Mar. Resources Agency, Dept. Fish Game. Marine Resources Leaflet #8: 16 pp.

May, R. C. 1974a. Effects of temperature and salinity on yolk utilization in *Bairdiella icistia* (Jordan and Gilbert) (Pisces: Sciaenidae). J. Exp. Mar. Biol. Ecol. 16: 213–225. **M**

May, R. C. 1974b. Factors affecting buoyancy in the eggs of *Bairdiella icistia* Mar. Biol. 28: 55–59.

May, R. C. 1975a. Effects of temperature and salinity on fertilization, embryonic development, and hatching in *Bairdiella icistius* (Pisces: Sciaenidae), and the effect of parental salinity acclimation on embryonic and larval salinity tolerance. Calif. Dept. Fish Game, Fish. Bull. 73: 1–22. **M**

May, R. C. 1975b. Effects of acclimation on the temperature and salinity tolerance of the yolk-sac larvae of *Bairdiella icistia* (Pisces: Sciaenidae). Calif. Dept. Fish Game, Fish. Bull. 73: 249–255. **M**

May, R. C. 1976. Effects of Salton Sea water on the eggs and larvae of *Bairdiella icistia* (Pisces: Sciaenidae). Calif. Fish Game, 62: 119–131. **M**

May, R. V. 1975. A brief survey of Kumeyaay ethnography: correlations between environmental land-use patterns, material culture, and social organization. Pacific Coast Archaeol. Soc. Quart. 11: 1–25.

Mayhew, W. W. 1995. Amphibians of the California desert. pp. 305–315 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA. **M**

McAda, C. W., and R. S. Wydowoski. 1980. The razorback sucker, *Xyrauchen texanus,* in the upper Colorado River Basin, 1974–1976. Tech. Papers US Fish Wildlife Serv. 99: 1–15.

McCaskie, G. 1970. Shorebird and waterbird use of the Salton Sea. Calif. Fish Game, 56: 87–95. (abstract)

McCaskie, G., and S. Suffel. 1971. Black skimmers at the Salton Sea, California. Calif. Birds, 2: 69–71.

McCaskie, G., S. Liston, and W. A. Rapley. 1974. First nesting of black skimmers in California. Condor, 76: 337–338.

McClanahan, L. L., R. Ruibal, and V. H. Shoemaker. 1994. Frogs and toads in deserts. Sci. Amer. (March): 82–88. **M**

McClurg, S. 1994. The Salton Sea: the environmental and economic values of this vast inland lake prompt local officials to launch a new restoration effort. Western Water (March/April): 3–11.

McCown, B. E. 1955. The Lake LeConte beach line survey. Masterkey, 29: 89–92.

McCullough, F. S., and A. Malek. 1984. Notes on the molluscan intermediate hosts of *Paragonimus* spp. and their possible role in biological control. Ann. Trop. Med. Parasit. 78: 339–340. **M**

McDonald, C. C., and O. J. Loeltz. 1976. Water Resources of the Lower Colorado River-Salton Sea as of 1971: Summary Report. US Geol. Surv. Prof. Pap. 486-A. 34 pp.

McDonald, J. H., R. Seed, and R. K. Kohn. 1991. Allozymes and morphometric characters of three species of *Mytilus* in the northern and southern hemispheres. Mar. Ecol. Prog. Ser. 111: 323–333. **M**

McDougall, K., C. L. Powell, J. C. Matti, and R. Z. Poore. 1994. The Imperial Formation and the opening of the ancestral Gulf of California. Geol. Soc. Amer. Abstracts with Programs, 26 (2): 71.

McKelvey, N. 1950. The indomitable Epes Randolph: physical weakness did not handicap Harriman's right-hand man when Southern Pacific fought to save its line in the Imperial Valley. Trains, 10 (9): 44–49.

McKenney, J. W. 1950. He named Lake Cahuilla. Desert Mag. 13 (March): 11–13.

McKibben, M. A. ed. 1991a. The Diversity of Mineral & Energy Resources of Southern California. Soc. Econom. Geol., Ft. Collins CO. Guidebook Ser. #12. 156 pp.

McKibben, M. A. 1991b. Introduction to the Salton Trough rift. pp. 77–86 in M. A. McKibben, ed. The Diversity of Mineral and Energy Resources of Southern California. Soc. Econom. Geol., Ft. Collins CO. Guidebook Ser. #12.

McKibben, M. A. 1993. The Salton Trough rift. pp. 76–80 in R. E. Reynolds and J. Reynolds, eds. Ashes, Faults, and Basins. San Bernardino Co. Assoc. Sp. Publ. 93. **M**

McKnight, S. K., and G. R. Hepp. 1995. Potential effect of grass carp herbivory on waterfowl foods. J. Wildlife Manag. 59: 720–727. **M**

Means, E. A. 1907. Mammals of the Mexican boundary with the United States. US National Mus. Bull. 56: 1–530.

Mearns, A. J. 1975. *Poeciliopsis gracilis* (Haeckel), a newly introduced poeciliid fish in California. Calif. Fish Game, 61: 251–253. **M**

Mearns, A. J. 1979. Pollutant flow through marine food webs. pp. 107–117 in S. J. Lipovsky and C. A. Simenstad, eds. Gutshop '78. Fish Food Habits Studies. Proc. 2nd. Pacific Northwest Tech. Workshop. Washington Sea Grant Publ. WSG-WO-79-1. **M**

Mearns, A. J., and D. J. Reish. 1969. A comparison of the free amino acids in two populations of the polychaetous annelid *Neanthes succinea*. South. Calif. Acad. Sci. Bull. 68: 43–53.

Meidav, T. 1968. Structural characteristics of the Salton Sea, California. Amer. Geophys. Union, Trans. 49(1): 758, Abstract V6.

Melack, J. M., and R. Jellison. 1998. Limnological conditions in Mono Lake: contrasting monomixis and meromixis. Hydrobiologia, 384: 21–39. **M**

Mellink, E. 1995. Status of the muskrat in the Valle de Mexicali and Delta del Río Colorado, Mexico. Calif. Fish Game, 81: 33–38. **M**

Mellink, E., and V. Ferreira-Bartrina. 2000. On the wildlife of wetlands of the Mexican portion of the Rio Colorado delta. South. Calif. Acad. Sci. Bull. 99: 115–127. **M**

Mellink, E., and J. Luevano. 1998. Status of beavers (*Castor canadensis*) in the Valle de Mexicali, Mexico. South. Calif. Acad. Sci. Bull. 97: 115–120.

Mellink, E., E. Palacios, and S. Gonzalez. 1997a. Notes on the nesting birds of the Cienega de Santa Clara saltflat, northwestern Sonora, Mexico. Western Birds, 27: 202–203.

Mellink, E., E. Palacios, and S. Gonzalez. 1997b. Non-breeding waterbirds of the delta of the Rio Colorado, Mexico. J. Field Ornithol. 68: 1113–123.

Mendenhall, W. C. 1907. The Colorado Desert, California. US Geol. Surv. Open-file Rep. 9 pp.

Mendenhall, W. C. 1909. Ground waters of the Indio region, California, with a sketch of the Colorado Desert. US Geol. Surv. Water-supply Pap. 225: 1–56.

Merriam, R., and O. L. Bandy. 1965. Source of Upper Cenozoic sediments in Colorado Delta region. J. Sediment. Petrology, 35: 911–916.

Meteyer, C. U., R. R. Dubielzig, F. J. Dein, L. A. Baeten, M. K. Moore, J. R. Jehl, Jr., and K. Wesenberg. 1997. Sodium toxicity and pathology associated with exposure of waterfowl to hypersaline playa lakes of southeast New Mexico. J. Veterin. Diag. Invest. 9: 269–280. **M**

Metzner, C. G., ed. 1988. Water Quality Issues of the California-Baja California Border Region. San Diego St. Univ. Inst. Regional Studies California, San Diego CA., Border Issues Ser. #4. 83.

Meyer, G. L. 1979a. Aeolian features of northern Coachella Valley and landforms and tectonic features of the San Andreas Fault zone in the Indio Hills. Field trip #1 in Field Guide for 1979 Spring Conference. National Assoc. Geol. Teachers, Far Western Sect., Field Guide 25.

Meyer, G. L. 1979b. Martinez Mountain landslide and shoreline features of prehistoric Lake Cahuilla, southwest margin of Coachella Valley. Field trip #3 in Field Guide for 1979 Spring Conference. National Assoc. Geol. Teachers, Far Western Sect., Field Guide 25.

Michel, M. 2000. Preserving archaeology and ecology. Amer. Archaeol. 4(4): 2. **M**

Michel, R. L., and R. A. Schroeder. 1994. Use of long-term tritium records from the Colorado River to determine time scales for hydrologic processes associated with irrigation in the Imperial-Valley, California. Appl. Geochem. 9: 387–401.

Micklin, P. P. 1988. Desiccation of the Aral Sea: a water management disaster in the Soviet Union. Science 241: 1170–1176. **M**

Miller, D. M. 2000a. Geology and seismicity of the Salton Basin. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract)

Miller, D. M. 2000b. Earthquakes: planning for ground rupture hazards. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Miller, L., and A. J. van Rossem. 1929. Nesting of the laughing gull in southern California. Condor 31: 141–142.

Miller, R. R. 1943. The status of *Cyprinodon macularius* and *Cyprinodon nevadensis,* two desert fishes of western North America. Univ. Michigan Mus. Zool. Occas. Pap. 473: 1–25.

Miller, R. R. 1946. The probable origin of the soft-shelled turtle in the Rio Colorado basin. Copeia, 1946: 46.

Minckley, W. L. 1982. Trophic interactions among introduced fishes in the lower Rio Colorado, southwestern United States. Calif. Fish Game, 68: 78–89.

Minckley, W. L. 1983. Status of the razorback sucker *Xyrauchen texanus* (Abbott) in the lower Colorado River basin. Southwestern Naturalist, 28: 165–187.

Minckley W. L. and B. D. DeMarias. 2000. Taxonomy of chubs (Teleostei, Cyprinidae, genus *Gila*) in the American southwest with comments on conservation. Copeia 2000: 251–256.

Minklin, P. P., and W. D. Williams, eds. 1966. The Aral Sea Basin. NATO Adv. Sci. Inst. Ser., Partnership Subser. 2, vol. 12. Springer-Verlag, Berlin, Germany. 186 pp.

Mitchell, E. 1906. The Salton Sea. North Amer. Rev. 183: 224–236.

Miyazaki, H., T. Kaneko, S. Hasegawa, and T. Hirano. 1998. Developmental changes in drinking rate and ion and water permeability during early life stages of euryhaline tilapia, *Oreochromis mossambicus,* reared in freshwater and seawater. Fish Physiol. Biochem. 18: 277–284. **M**

Mkoji, G. M., T. G. Boyce, B. N. Mungai, R. S. Copeland, B. V. Hofkin, and E. S. Loder. 1999. Predation on aquatic stages of *Anopheles gambiae* by the Louisiana red swamp crayfish (*Procambarus clarkii*). J. Amer. Mosq. Control Assoc. 15: 69–71. **M**

Molina, K. C. 1996. Population status and breeding biology of black skimmers at the Salton Sea, California. Western Birds, 27: 143–158. (abstract) **M**

Mono Lake Ecosystem Study Committee. 1987. The Mono Basin Ecosystem: Effects of Changing Lake Level. Natural Res. Council Comm. Phys. Sci. Math. Resources, Bd. Environ. Studies Toxicol. Mono Basin Ecosystem Study Comm. National Acad. Press, Washington DC. 272 pp. **M**

Montano, A., and G. C. Holdren. 2000. Seasonal variation of nutrient, major ion, and metal concentrations in the Salton Sea, 1999. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract)

Moore, C. V., J. H. Snyder, and P. Sun. 1974. Effects of Colorado River water quality and supply on irrigated agriculture. Water Resources Res. 10: 137–144.

Moore, I., and E. F. Legner. 1973. Speculation on the distribution of the southern California species of *Cafius* with a new record from the Salton Sea (Coleoptera: Staphylinidae). Pan-Pacific Entomol. 49: 279–280. **M**

Moore, P. 2000. A new life for the New River. Outdoor Calif. 61(5): 16–19. **M**

Mora, M. A. 1989. Predation by a brown pelican at a mixed species heronry. Condor, 91: 742–743.

Mora, M. A. 1991. Organochlorines and breeding success in cattle egrets from the Mexicali Valley, Baja California, Mexico. Colonial Waterbirds, 14: 127–132. **M**

Mora, M. A. 1997. Feeding flights of cattle egrets nesting in an agricultural ecosystem. Southwestern Naturalist, 42: 52–58.

Mora, M. A., and D. W. Anderson. 1995. Selenium, boron, and heavy metals in birds from the Mexicali Valley, Baja California, Mexico. Bull. Environ. Contam. Toxicol. 54: 198–206.

Mora, M. A., D. W. Anderson, and M. E. Mount. 1987. Seasonal variation of body condition and organochlorines in wild ducks from California and Mexico. J. Wildlife Manage. 51: 132–141.

Morgan, J. D., T. Sakamoto, E. G. Grau, and G. K. Iwama. 1997. Physiological and respiratory responses of the Mozambique tilapia (*Oreochromis mossambicus*) in salinity acclimation. Comp. Biochem. Physiol. 117A: 391–398.

Morris, R. H., D. P. Abbott, and E. C. Haderlie, eds. 1980. Intertidal Invertebrates of California. Stanford Univ. Press, Stanford CA. 590 pp.

Morris, R. M., E. A. Keller, and G. L. Meyer. 1979. Geomorphology of the Salton Basin, California: selected observations. pp. 19–64 in P. L. Abbott, ed. Geological Excursions in the Southern California Area. San Diego St. Univ., San Diego CA.

Morrison, J. P. E. 1954. The relationships of old and new world melanians. US National Mus. Proc. 103: 357–394. **M**

Morton, B,, and D. Dudgeon, eds. 1980. The Malacofauna of Hong Kong and Southern China. Hong Kong Univ. Press, Hong Kong. 345 pp.

Morton, P. K. 1977. Geology and Mineral Resources of Imperial County California. Calif. Div. Mines Geol. County Report #7.

Moss, B. 1988. Ecology of Fresh Waters: Man and Medium. 2nd. ed. Blackwell Sci. Publ. London. 417 pp. **M**

Mount, J. D. 1988. Molluscan fauna of the Imperial Formation. pp. 23–24 in S. M. Testa and K. E. Green, eds. Geologic Field Guide to the Western Salton Basin Area. Amer. Inst. Prof. Geol.

Moyle, P. B. 1973. Effects of introduced bullfrogs, *Rana catesbeiana,* on the native frogs of the San Joaquin Valley, California. Copeia, 1973: 18–22.

Moyle, P. B. 1976. Inland Fishes of California. Univ. Calif. Press, Berkeley CA. 405 pp. **M**

Moyle, W. R., Jr. 1968. Water wells and springs in Borrego, Carrizo, and San Felipe Valley areas, San Diego and Imperial Counties, California. Calif. Dept. Water Resources Bull. 91–15: 140 pp.

Muffler, L. J. P., and B. R. Doe. 1968. Composition and mean age of detritus of the Colorado River delta in the Salton Trough, southeastern California. J. Sediment. Petrol. 38: 384–399.

Muffler, L. J. P., and D. E. White. 1969. Active metamorphism of upper Cenozoic sediments in the Salton Sea geothermal and Salton Trough, southeastern California. Geol. Soc. Amer. Bull. 80: 157–182. **M**

Mule, M. B., and V. S. Lomte. 1994. Effect of heavy metals ($CuSO_4$ and $HgCl_2$) on the oxygen consumption of the freshwater snail, *Thiara tuberculata.* J. Environ. Biol. 15: 263–268.

Mullens, B. A., and C. E. Dada. 1992. Insects feeding on desert bighorn sheep, domestic rabbits, and Japanese quail in the Santa Rosa Mountains of Southern California. J. Wildlife Diseases, 28: 476–480. **M**

Murashige, R., P. Bass, L. Wallace, A. Molnar, B. Eastham, V. Sato, C. Tamaru, and C. S. Lee. 1991. The effect of salinity of the survival and growth of striped mullet (*Mugil cephalus*) in the hatchery. Aquaculture, 96: 249–254.

Murbarger, N. 1952. He was monarch of Mullet Island. Palms Springs Villager, May 1952.

Murphy, R. C. 1917. Natural history observations from the Mexican portion of the Colorado Desert. Abs. Linnaean Soc. 24–25: 43–101.

Murray, H. D. 1964. *Tarebia granifera* and *Melanoides tuberculata* in Texas. Amer. Malacol. Union Ann. Rep. 31: 15–16. **M**

Murray, H. D. 1966. Ecology of *Melanoides tuberculata* and *Tarebia granifera* in Texas. Texas Shell News (San Antonio Shell Club) 9(4): 7–8.

Murray, H. D. 1970. Discussion of Dr. Taylor's paper [on western freshwater molluscs]. Malacologia, 10: 33–34. **M**

Murray, H. D. 1971a. Introduction and spread of thiarids in the United States. Amer. Malacol. Union Ann. Rep. 37: 55. (abstract)

Murray, H. D. 1971b. The introduction and spread of thiarids in the United States. Biologist, 53: 133–135. **M**

Murray, H. D. 1975. *Melanoides tuberculata* (Müller), Las Moras Creek, Bracketville, Texas. Amer. Malacol. Union Bull. 1975: 43. **M**

Murray, H. D. 1982. Histology of the testis of *Tarebia granifera.* Amer. Malacol. Union Bull. 1: 95–96. **M**

Murray, H. D., and D. Haines. 1969. *Philophthalmus* sp. (Trematoda) in *Tarebia granifera* and *Melanoides tuberculatus* in south Texas. Amer. Malacol. Union Ann. Rep. 1969: 44–45. **M**

Murray, H. D., and A. J. Stewart. 1968. Establishment of a trematode cycle in *Tarebia granifera* (Lamarck) in Texas. Amer. Malacol. Union Ann. Rep. 35: 17–18. **M**

Murray, H. D., and L. J. Wopschall. 1965. Ecology of *Melanoides tuberculata* (Müller) and *Tarebia granifera* (Lamarck) in south Texas. Amer. Malacol. Union Ann. Rep. 165: 25–26. **M**

Nabham, G., and J. M. J. de Wet. 1984. *Panicum sonorum* in Sonora Desert agriculture. Econ. Botany, 38: 65–82.

Naiman, R. J. 1979. Preliminary food studies of *Cyprinodon macularius* and *Cyprinodon nevadensis* (Cyprinodontidae). Southwestern Naturalist, 24: 538–541.

Naiman, R. J., and D. L. Soltz, eds. 1981. Fishes in North American Deserts. Wiley-Interscience, New York City. 552 pp.

Nathanson, S. 1972. The Finney-Ramer unit, Imperial Wildlife Area. Outdoor Calif. 33 (6): 13–15. **M**

National Geographic Society. 1999. Field Guide to the Birds of North America. 3rd. ed. National Geog. Soc., Washington DC. 480 pp. **M**

National Wetlands Inventory. 1993. Salton Sea (Salton Sea SW) National Wildlife Inventory. National Wetlands Inventory, St. Petersburg FL Rep. 33115-A- 1–D8. 4 microfiche.

Nava, F. A., and E. Glowacka. 1999. Fault-slip triggering, healing, and viscoelastic afterworking in sediments in the Mexicali-Imperial Valley. Pure Appl. Geophys. 156: 615–629.

Newall, F. H. 1908. The Salton Sea. Smithsonian Report for 1907, Washington DC. 331–345.

Newman, J., ed. 1991. Layperson's Guide to the Colorado River. Western Water Education Foundation, Sacramento CA. 28 pp. **M**

Newman, R. A., and D. P. Abbott. 1980. Cirripedia: the barnacles. pp. 504–524 in R. H. Morris, D. P. Abbott, and E. C. Haderlie, eds. Intertidal Invertebrates of California. Stanford Univ. Press, Stanford CA. **M**

Newmark, R. L., P. W. Kasameyer, and L. W. Younker. 1986. Shallow drilling in the Salton Sea region: the thermal anomaly. J. Geophys. Res. 93: 13005–13024.

Nicola, S. J. 1979. Fisheries problems associated with the development of the lower Colorado River. Calif. Dept. Fish Game, Inland Fish. Endangered Spec. Prog. Sp. Publ. 79–4. 18 pp. **M**

Niehuis, 1939. Lost ship of the desert. Desert Mag. 2 (January): 12–14.

Noble, E. R., R. E. King, and B. L. Jacobs. 1963. Ecology of the gill parasites of *Gillichthys mirabilis* Cooper. Ecology 44: 295–305.

Noble, E. R., G. A. Noble, G. A. Schad, and A. J. MacInness. 1989. Parasitology: The Biology of Animal Parasites. 6th ed. Lea and Febiger, Philadelphia PA. 574 pp. **M**

Nordland, O. J., ed. 1978. Coachella Valley's Golden Years: the Early History of the Coachella Valley County Water District and Stories about the Discovery and Development of this Section of the Colorado Desert. Revised ed. Coachella Valley Water District, Indio CA. Desert Printing Co., Indio CA. 120 pp. **M**

Nordlie, F. G., D. C. Haney, and S. J. Walsh. 1992. Comparisons of salinity tolerances and osmotic regulatory capabilities in populations of sailfin molly (*Poecilia latipinna*) from brackish and fresh waters. Copeia 1992: 741–746. (abstract) **M**

Norris, R. M. 1966. Barchan dunes of Imperial Valley, California. J. Geol. 74: 292–306.

Norris, R. M. 1995a. Sand dunes of the California desert. pp. 15–25 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Norris, R. M. 1995b. Geology of the California deserts: a summary. pp. 27–58 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA. **M**

Norris, R. M., and K. S. Norris. 1961. Algodones Dunes of southeastern California. Geol. Soc. Amer. Bull. 72: 605–619.

Norris, R. M., and R. W. Webb. 1990. Geology of California. 2nd ed. John Wiley, New York City NY. 541 pp. **M**

Norris, R. M., E. A. Keller, and G. L. Meyer. 1979. Geomorphology of the Salton Basin, California: selected observations. in P. L. Abbott, ed. Geological Excursions in the Southern California Area. Guidebook for 1979 Ann. Meeting, Geol. Soc. Amer. Reprinted as pp. 213–224. in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

O'Connor, J. E., L. L. Ely, E. E. Wohl, L. E. Stevens, T. S. Melis, V. S. Kale, and V. R. Baker. 1994. A 4500 year record of large floods on the Colorado River in the Grand Canyon, Arizona. J. Geol. 102:109. **M**

Oertle, V. L. 1964. Salton Sea Recreation Guide. Desert-Southwest Publ. Co. Palm Desert CA. 56 pp. **M**

Ogden Environmental and Energy Services. 1996. Salton Sea Management Project: Evaluation of Salinity and Elevation Management Alternatives. Prepared for Salton Sea Authority by Ogden Environmental and Energy Services, San Diego. Variously paginated.

Oglesby, L. C. 1965. Steady-state parameters of water and chloride regulation in estuarine nereid polychaetes. Comp. Biochem. Physiol. 14: 621–640. **M**

Oglesby, L. C. 1977. A newly introduced, brackish-water snail in the Salton Sea basin, California. Calif. Fish Game, 63: 180–183. **M**

Oglesby, L. C. 1978. Salt and water balance. pp. 555–668 in P. J. Mill, ed. Physiology of the Annelida. Academic Press, London. **M**

Oglesby, L. C. 1980. Responses to higher salinities by the euryhaline snail *Thiara granifera*. Amer. Zool. 20: 873. **M**

Oglesby, L. C. 1993. Ecology and physiology of two species of aquatic Old-World prosobranch snails

introduced in the Coachella Valley. San Bernardino County Mus. Assoc. Quart. 40 (2): 28–29. **M**

Ohlendorf, H. M., and K. C. Marois. 1990. Organochlorines and selenium in California night-heron and egret eggs. Environ. Monit. Assess. 15: 91–104. **M**

Ohlendorf, H. M., and M. R. Miller. 1984. Organochlorine contaminants in California wildfowl. J. Wildlife Manag. 48: 867–877.

Ohlendorf, H. M., R. L. Hothem, C. M. Bunck, and C. C. Marois. 1990. Bioaccumulation of selenium in birds at Kesterson Reservoir, California. Arch. Environ. Contam. Toxicol. 19: 495–507.

Ohmart, R. D. 1978. Habitat requirements and population characteristics of the clapper rail (*Rallus longirostris yumanensis*) in the Imperial Valley of California. Univ. Calif. Lawrence Livermore National Laboratory. UCRL-13813. 55 pp.

Ohmart, R. D., B. W. Anderson, and W. C. Hunter. 1985. Influence of agriculture on waterbird, water, and shorebird use along the lower Rio Colorado. pp. 117–122 in R. R. Johnson, C. D. Ziebell, D. R. Patton, P. F. Folliott, and R. H. Hamre, eds. Riparian Ecosystems and their Management: Reconciling Conflicting Uses. Memorias del 1st North American Riparian Conference. Rocky Mountain Forest and Range Experiment Station. Tucson AZ.

Ohmart, R. D., B. W. Anderson, and W. C. Hunter. 1988. The Ecology of the Lower Rio Colorado from Davis Dam to the Mexico-United States Border: a Community Profile. US Fish Wildlife Serv. Biol. Reports 85 (7.19). US Fish Wildlife Serv., Washington DC. 298 pp.

Oliver, J. D. 1993. A review of the biology of giant salvinia (*Salvinia molesta* Mitchell). J. Aquat. Plant Manag. 31: 227–231. **M**

Orcutt, C. R. 1888. Fishing on the Colorado Desert. West Amer. Sci. 5: 2–4.

O'Reilly, J. 1957. A fighting fish for the Salton Sea. Sports Illustr. (August): 29–31.

Ornithological Council. 1998. The Salton Sea: a bird's eye view. Bird Issue Brief 1 (6). **M**

Ostro, B. D., S. Hurley, and M. J. Lipsett. 1999. Air pollution and daily mortality in the Coachella Valley, California: a case study of PM10 dominated by coarse particles. Environ. Res. 81: 231–238. **M**

Owens, A, T. Wigham, B. Doneen, and H. A. Bern. 1977. Effects of environmental salinity and of hormones on urinary bladder function in the euryhaline teleost, *Gillichthys mirabilis*. Gen. Comp. Endocrinol. 33: 526–530. **M**

Pacific Institute. 2000. Comments on the Salton Sea Restoration Project and the Salton Sea Restoration Project Draft Environmental Impact Statement Environmental Impact Report. Pacific Inst. Studies Develop. Environ. Security, Oakland CA. 18 pp.

Page, G. W., and L. E. Stenzel. 1981. The breeding status of the snowy plover in California. Western Birds, 12: 1–40.

Page, G. W., L. E. Stenzel, W. D. Shuford, and C. R. Bruce. 1991. Distribution and abundance of the snowy plover on its western North American breeding grounds. J. Field Ornithol. 62: 245–255.

Page, G. W., W. D. Shuford, J. E. Kjelmyer, and L. E. Stenzel. 1992. Shorebird numbers in wetlands of the Pacific Flyway: a summary of counts from April 1988 to January 1992. Point Reyes Bird Observatory, Palomarin CA. Rep. (abstract)

Pallette, D. 1973. Coachella Valley prehistory: a brief chronology. pp. 64–66 in R. E. Reynolds and J. Reynolds, eds. Ashes, Faults and Basins. The 1993 Mojave Desert Quaternary Research Center Field Trip. San Bernardino County Mus. Assoc. Sp. Publ. 93–1.

Papoulias, D., and W. L. Minckley. 1990. Food limited survival of larval razorback sucker, *Xyrauchen texanus* in the laboratory. Environ. Biol. Fishes 29: 73–78.

Parish, S. B. 1914. Plant ecology and floristics of Salton Sink. pp. 85–103 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L.

Parker, M. S., and A. W. Knight. 1992. Aquatic invertebrates inhabiting saline evaporation ponds in the southern San Joaquin Valley, California. South. Calif. Acad. Sci. Bull. 91: 39–43. **M**

Parnell, J. F., R. M. Erwin, and K. C. Molina. 1995. Gull-billed tern (*Sterna nilotica*). Birds North Amer. #140. Acad. Nat. Sci. Philadelphia.

Parsons Corporation. 1985. Water Requirements and Availability Study and Water Transfer Study. Water Conservation Program, Imperial Irrigation District. Executive Summaries. Parsons Water Resources Inc. **M**

Patencio, F. 1943. Stories and Legends of the Palm Springs Indians. M. Boynton, ed. Times-Mirror Co., Los Angeles CA. 132 pp.

Patencio, F. 1971. Desert Hours with Chief Patencio, as Told to Kate Collins by Chief Francisco Patencio. R. F. Hudson, ed. Palm Springs Desert Museum., Palm Springs CA. 38 pp. **M**

Patten, M. A., and R. A. Minnich. 1997. Procellariiformes occurrences at the Salton Sea and Sonoran desert. Southwestern Naturalist, 42: 302–311. **M**

Pearson, G., and C. W. Conner. 2000. The Quitobaquito desert pupfish, an endangered species within Organ Pipe National Monument: historical significance and management challenges. Natural Res. J. 40: 379–410. (abstract)

Peirce, G. J. 1914. Behavior of certain micro-organisms in brine. pp. 49–70 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L: 49–70.

Pelzman, R. 1974. A review of the life history of *Tilapia zillii* with a reassessment of its desirability in California. Calif. Dept. Fish Game. Inland Fisheries Admin. Rep. 74–1.

Pemberton, J. R. 1927. The American gull-billed tern breeding in California. Condor, 29: 253–258. (abstract)

Pepper, C. 1972. Guidebook to the Colorado Deserts of California, Including Palm Springs, Salton Sea, Indio and the Colorado River. Ward Ritchie Press, Los Angeles. 128 pp. **M**

Pepper, C. 1999. Desert Lore of Southern California. 2nd ed. Sunbelt Publ., San Diego CA. 174 pp. **M**

Perez, A. L. E. 1994. The Effects of Increasing Salinity on the Reproduction, Feeding Behavior, Growth Rate, Osmoregulation and Survival of the Barnacle *Balanus amphitrite* (Crustacea, Thoracica) from the Salton Sea, California. MS thesis, Loma Linda Univ., Loma Linda CA. **M**

Perez, J. G., M. Vargas. and E. A. Malek. 1991. Displacement of *Biomphalaria glabrata* by *Thiara granifera* under natural conditions in the Dominican Republic. Mem. Inst. Oswaldo Cruz, 86: 341–347.

Peterjohn, B. G., and J. R. Sauer. 1998. Population trends of black terns from the North American Breeding Bird Survey, 1966–1996. Colonial Waterbirds, 20: 566–573.

Pettibone, M. H. 1963. Marine polychaete worms of the New England region. 1. Aphroditidae through Trochochaetidae. Smithsonian Inst. Bull. 227: 1–356. **M**

Phelps, H. L. 1994. The Asiatic clam (*Corbicula fluminea*) invasion and system-level ecological change in the Potomac River estuary near Washington, DC. Estuaries, 17: 614–621. **M**

Phelps, P. L., and L. R. Anspaugh, eds. 1976. Imperial Valley Environmental Project: Progress Report. Univ. Calif. Lawrence Livermore National Laboratory. UCRL-50044-76-1. 214 pp. **M**

Pigñiolo, A. R. 1994. The rainbow rock wonderstone source and its place in regional material distribution studies. Soc. Calif. Archaeol. Proc. 8: 123–132.

Pigñiolo, A. R., and D. Gallegos. 1989. Cultural Resource Survey and Site Evaluation of the Monofill Project Area and Access Road, Imperial County, California. ERC Environmental, San Diego CA.

Pimentel, K. D., R. R. Ireland, and G. A. Tompkins. 1978. Chemical fingerprints to assess the effects of geothermal development on water quality in Imperial Valley. Univ. Calif. Lawrence Livermore National Laboratory, Preprint UCRL-81177: 1–4.

Pisano, M. S., M. J. Inansci, and W. L. Minckley. 1983. Age and growth and length-weight relationship for flathead catfish, *Pylodictis olivaris,* from Coachella Canal, southeastern California. Calif. Fish Game, 69: 124–128.

Pister, E. P. 1995. Fishes of the California Desert Conservation Area. pp. 285–303 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA. **M**

Pitman, J. K., and A. R. Carroll, eds. 1998. Modern & Ancient Lake Systems: New Problems and Perspectives. Utah Geol. Assoc. Salt Lake City UT, Guidebook #26. 328 pp.

Platt, S., and W. Hauser. 1978. Optimum temperature for feeding and growth of *Tilapia zillii.* Progressive Fish-Culturist, 40: 105–107.

Platter, M. F. 1976. Breeding Ecology of Cattle Egrets and Snowy Egrets at the Salton Sea, Southern California. MS thesis, San Diego State Univ., San Diego CA. 122 pp. (abstract) **M**

Platz, J. E., R. W. Clarkson, J. C. Rorabaugh, and D. M. Hillis. 1990. *Rana berlandieri*: recently introduction populations in Arizona and southeastern California. Copeia, 1990: 324–333.

Pointier, J.-P. 1993. The introduction of *Melanoides tuberculata* (Mollusca Thiaridae) to the Island of Saint Lucia (West Indies) and its role in the decline of *Biomphalaria glabrata,* the snail intermediate host of *Schistosoma mansoni.* Acta Tropica, 54: 13–18. (abstract)

Pointier, J.-P. 1999. Invading freshwater gastropods: some conflicting aspects for public health. Malacologia, 41: 403–411. **M**

Pointier, J.-P., and D. Augustin. 1999. Biological control and invading freshwater snails: a case study. C. R. Acad. Sci. Ser. III Sci. Vie, 322: 1093–1098. **M**

Pointier, J.-P., L. Thaler, A. F. Pernot, and B. Delay. 1993a. Invasion of Martinique island by the parthenogenetic snail *Melanoides tuberculata* and the succession of morphs. Acta Oecol. 14: 33–42. (abstract) **M**

Pointier, J.-P., A. Theron, and G. Borel. 1993b. Ecology of the introduced snail *Melanoides tuberculata* (Gastropoda: Thiaridae) in relation to *Biomphalaria glabrata* in the marshy forest zone of Guadeloupe, French West Indies. J. Molluscan Studies, 59: 421–428. (abstract) **M**

Pointier, J.-P., R. N. Incani, C. Balzan, P. Chrosciechowski, and S. Prypchan. 1994. Invasion of the rivers of the littoral central region of Venezuela by *Thiara granifera* and *Melanoides tuberculata* (Mollusca, Prosobranchia, Thiaridae) and the absence of *Biomphalaria glabrata*, snail host of *Schistosoma mansoni*. Nautilus, 107: 124–128.

Pointier, J.-P., S. Samadi, P. Jarne, and B. Delay. 1998. Introduction and spread of *Thiara granifera* (Lamarck, 1822) in Martinique, French West Indies. Biodivers. Conserv. 7: 1277–1297. **M**

Pomento, J. 1998. The Salton Sea: can it be saved? Aqueduct 2000 (Metropolitan Water District) (2): 2–3. **M**

Pomeroy, R. D., and H. Cruse. 1965. A Reconnaissance Study and Preliminary Report on a Water Quality Control Plan for Salton Sea. Prepared for Calif. State Water Qual. Control Bd. by Pomeroy, Johnston and Bailey Engineers, Pasadena CA 190 pp. **M**

Pontius, D. 1997. Colorado River Basin Study: Final Report. Rep. for Western Water Policy Review Advisory Commission, Denver CO. 132 pp.

Popenoe, F. W. 1963. Coachella Valley, geological evolution: ocean to grassland to desert. Desert Mag. 26 (3): 12–17.

Popper, D., and T. Lichatowich. 1975. Preliminary success in predator contact of *Tilapia mossambica*. Aquaculture 5: 213–214. (abstract)

Postma, H. 1967. Sediment transport and sedimentation in the estuarine environment. pp. 158–179 in G. H. Lauff, ed. Estuaries. Amer. Assoc. Adv. Sci., Washington DC. **M**

Potts, W. T., and G. Perry. 1964. International Series of Monographs on Pure and Applied Biology. Volume 19. Osmotic and Ionic Regulation in Animals p. 90. Pergamon Press, Oxford. **M**

Potts, W. T. W., M. A. Foster, P. P. Rudy, and G. P. Howells. 1967. Sodium and water balance in the cichlid teleost, *Tilapia mossambica*. J. Exp. Biol. 47: 461–470. **M**

Powell, C. L., II. 1995. Preliminary report on the Echinodermata from the Miocene and Pliocene of the Coyote Mountains, southern California. pp. 55–63. in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol., San Diego CA. **M**

Powell, F., ed. 1976. Heritage Tales of Coachella Valley. Amer. Assoc. Univ. Women, Palm Springs Branch, Palm Desert CA. 65 pp.

Powell, J. W. 1891a. The new lake in the desert. Scribner's Mag. 10: 463–468.

Powell, J. W. 1891b. The flooding of the Colorado Desert. Engineer. Mining J. 52: 9.

Powell, R. E., R. J. Weldon, and J. C. Matti, eds. 1993, The San Andreas Fault System: Displacement, Palinspastic Reconstruction, and Geologic Evolution. Geol. Soc. Amer. Mem. 178: 332 pp.

Prather, B. G. 1964. Palm Springs Cahuilla Indians: notes on archaeological investigation of the Indio Area. San Bernardino Mus. Assoc. Quart. 12. 20 pp.

Premuzic, E. T., M. S. Lin, J. Z. Jin, and K. Hamilton. 1997. Geothermal waste treatment biotechnology. Energy Sources, 19: 9–17. **M**

Prentice, J. A. 1985. Orangemouth corvina survival in fresh water. Progressive Fish-Culturist, 47: 61–63. **M**

Prentice, J. A., and R. L. Colura. 1985. Preliminary observations of orangemouth corvina spawn inducement using photoperiod, temperature and salinity cycles. J. World Maricult. Soc. 15: 162–174. **M**

Prentice, J. A., and P. Thomas. 1987. Successful spawning of orangemouth corvina following injection with des-Gly^{10},[D-Ala^{6}]-luteinizing hormone-releasing hormone (1–9) ethylamide and pimozide. Progressive Fish-Culturist, 49: 66–69. **M**

Prentice, J. A., R. Colura, and B. Bumguardner. 1989. Observations in induced maturation and spawning of orangemouth corvina. Calif. Fish Game, 75: 27–32,

Presser, T. S. 1994. The Kesterson effect. Environ. Manag. 18: 437–454. **M**

Presser, T. S., T. S. Sylvester, and W. H. Low. 1994. Bioaccumulation of selenium from natural geological sources in western States and its potential consequences. Environ. Manag. 18: 423–436.

Preston, E. M. 1892. Salton Lake. Calif. St. Mining Bur. Rep. 11: 387–393.

Pringle, H. 1998. The sickness of mummies. Discover 19 (12): 74–83. **M**

Proctor, R. J. 1969. Geology of Desert Hot Springs-Upper Coachella Valley Area, California. Calif. Div. Mines Geol. Sp. Rep. 94. 50 pp.

Pryde, P. 1999. Understanding the Salton Sea problem: water transfers and the sea. Chaparral Naturalist (Pomona Valley Audubon Society). 39 (8): 3. **M**

Pryor, A. 1981. "Waste" claims threaten Imperial Valley water. Calif. Farmer, 6 June 1981. **M**

Qiu, J. W., and P. Y. Qian. 1999. Tolerance of the barnacle *Balanus amphitrite amphitrite* to salinity and temperature stress: effects of previous experience. Mar. Ecol. Prog. Ser. 188: 123–132. **M**

Quast, J. C. 1961. The food of the bairdiella [in the Salton Sea]. Calif. Fish Game, Fish Bull. 113: 153–164. **M**

Quinn, H. M. 1997. Observations on the Cahuilla Indians–Past and Present. Coachella Valley Archeol. Soc., Palm Springs CA, Occas. Pap #1. 46 pp.

Radtke, D. B., W. G. Kepner, and R. J. Effertz. 1988. Reconnaissance investigations of water quality, bottom sediment, and biota associated with irrigation drainage in the Lower Colorado River Valley, Arizona, California, and Nevada. 1986–1987. US Geol. Surv. Water Resources Investigat. Report, 88–4002.

Rahel, F. J. 2000. Homogenization of fish faunas across the United States. Science 288: 854–856.

Raibley, P. T., D. Blodgett, and R. E. Sparks. 1995. Evidence of grass carp (*Ctenopharyngodon idella*) reproduction in the Illinois and Mississippi Rivers. J. Freshwater Ecol. 10: 65–74. **M**

Raimondi, P. T. 1992. Adult plasticity and rapid larval evolution in a recently isolated barnacle population. Biol. Bull. 182: 210–230. **M**

Randall, W., T. Meidav, R. W. Rex, and L. Coursey. 1968. Electrical resistivity and geochemistry of aquifers in the Durmid Dome, Imperial Valley. Amer. Geophys. Union Trans. 49: 754 Abstract V7.

Real, C. R. 1979. Effects of Imperial Valley earthquake, 15 October 1979, Imperial County, California. Calif. Geol. 32: 259–265.

Redway, J. 1892. The new lake in the Colorado Desert, California. Roy. Geograph. Soc. Proc. 14: 309–314.

Redway, J. 1893. Salton Lake. Geograph. J. 2: 170–171.

Reifel, K. M., M. P. McCoy, M. A. Tiffany, S. H. Hurlbert, and D. J. Faulkner. 2000a. The possible importance of algal toxins: findings and prospects. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract). **M**

Reifel, K. M., M. A. Tiffany, M. P. McCoy, C. C. Trees, S. H. Hurlbert, and D. J. Faulkner. 2000b. *Pleurochrysis pseudoroscoffensis* in the Salton Sea, California. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Reisen, W. K., and H. D. Lothrop. 1995. Population ecology and dispersal of *Culex tarsalis* (Diptera: Culicidae) in the Coachella Valley of California. J. Med. Entomol. 32: 490–502. **M**

Reisen, W. K., H. D. Lothrop, S. B. Presser, M. M. Milby, J. L. Hardy, M. J. Wargo, and R. W. Emmons. 1995. Landscape ecology of arboviruses in southern California: temporal and spatial patterns of vector and virus activity in Coachella Valley, 1990–1992. J. Med. Entomol. 32: 179–188.

Reisen, W. K., R. E. Chiles, H. D. Lothrop, S. B. Presser, and J. L. Hardy. 1996. Prevalence of antibodies to mosquito-borne encephalitis viruses in residents of the Coachella Valley, California. Amer. J. Trop. Med. Hyg. 55: 667–671.

Reisen, W. K., H. D. Lothrop, and R. E. Chiles. 1998. Ecology of *Aëdes dorsalis* (Diptera: Culicidae) in relation to western equine encephalomyelitis virus in the Coachella Valley of California. J. Med. Entomol. 35: 561–566. **M**

Reisen, W. K., K. Boyce, R. C. Cummings, O. Delgado, A. Gutierrez, R. P. Meyer, and T. W. Scott.

1999. Comparative effectiveness of three adult mosquito sampling methods in habitats representative of four different biomes of California. J. Amer. Mosq. Control Assoc. 15: 24–31. **M**

Reisen, W. K., J. O. Lundstrom, T. W. Scott, B. F. Eldridge, R. E. Chiles, R. Cusack, V. M. Martinez, H. D. Lothrop, B. Gutierrez, S. E. Wright, K. Boyce, and B. R. Hill. 2000. Patterns of avian seroprevalence to western equine encephalomyelitis and St. Louis encephalitis viruses in California, US. J. Med. Entomol. 37: 507–527.

Reisner, M. 1993. Cadillac Desert: The American West and its Disappearing Water. Revised and updated. Penguin Books, New York City NY. 582 pp. **M**

Reisner, M., and S. Bates. 1990. Overtapped Oasis: Reform or Revolution for Western Water. Island Press, Washington DC. 200 pp.

Remeika, P. 1995a. Introduction: A visitor's perspective center-stage at Font's Point. pp. 1–2 in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol., San Diego CA. **M**

Remeika, P. 1995b. Basin tectonics, stratigraphy, and depositional environments of the western Salton Trough detachment. pp. 3–54 in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol., San Diego CA. **M**

Remeika, P. 1998. Marine invertebrate paleontology and stratigraphy of the Vallecito-Fish Creek Basin: a historic review, synthesis and revision. pp. 59–92 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. **M**

Remeika, P., and R. F. Fleming. 1995. Cretaceous palynoflora and Neogene angiosperm woods from Anza-Borrego Desert State Park, California: implications for Pliocene climate of the Colorado Plateau and age of the Grand Canyon. pp. 64–81. in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol. San Diego CA. **M**

Remeika, P., and G. T. Jefferson. 1995. The Borrego local fauna: revised basin-margin stratigraphy and paleontology of the western Borrego Badlands, Anza-Borrego Desert State Park, California. pp. 97–103 in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol., San Diego CA.

Remeika, P., and L. Lindsay. 1992. Geology of Anza-Borrego: Edge of Creation. Sunbelt Publ., San Diego CA and Kendall Hunt, Dubuque IA. 208 pp. **M**

Remeika, P., and A. Sturz, eds. 1995. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol., San Diego CA. **M**

Remeika, P., G. T. Jefferson, and L. K. Murray. 1995. Fossil vertebrate faunal list for the Vallecito-Fish Creek and Borrego-San Felipe Basins, Anza-Borrego Desert Sate Park and vicinity, California. pp. 82–93 in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol. San Diego CA.

Residencia General de Cerro Prieto. 1998. Cerro Prieto geothermal field. pp. 138–156 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. **M**

Rex, R. W. 1966. Heat flow in the Imperial Valley of California. Amer. Geophys. Union, Trans. 47: 181, Abstract T44.

Rex, R. W. 1968. Geochemical water facies in the Imperial Valley of California. Amer. Geophys. Union, Trans. 49: 758, Abstract V5.

Rex, R. W. 1971. Geothermal resources in the Imperial Valley. pp. 190–205 in D. Seckler, ed. California Water. A Study in Resource Management. Univ. Calif. Press, Berkeley CA.

Reynolds, R. E., and J. Reynolds, eds. 1992. Old Routes to the Colorado. San Bernardino County Mus. Assoc. Sp. Publ. 92–2. 106 pp.

Reynolds, R. E., and W. G. Turner. 1971. Petroglyph dating. San Bernardino Mus. Assoc. Quart. 19: 28–34. **M**

Riedel, R., and B. A. Costa-Pierce. 2000. Fish biology and fisheries ecology of the Salton Sea. Salton Sea Authority, Indian Wells CA. 28 pp. **M**

Riggs, A. C. 1984. Major carbon-14 deficiency in modern snail shells from southern Nevada springs. Science 224: 58–61. **M**

Rigsby, C. A., ed. 1984. The Imperial Basin: Tectonics, Sedimentation and Thermal Aspects. Soc. Econom. Paleontol. Mineral. Pacific Sec. 40. 95 pp.

Rinehart, R. B., and D. A. McFarlane. 1995. Early Holocene vegetation record from the Salton Basin, California. Quat. Res. 43: 59–262.

Rinne, W. E., and H. R. Guenther. 1979. Recent changes in habitat characteristics of the Santa Clara Slough, Sonora, Mexico. p. 44 in E. P. Pister, ed. Desert Fishes Council Proc. 11. **M**

Rinner, J. N. and H. M. Tyus. 1994. Bonytail chub. pp. 360–362 in C. G. Thelander, D. C. Pearson, and G. E. Olson, eds. Life on the Edge: A Guide to California's Endangered Natural Resources: Wildlife. Hey Day Books, Berkeley CA. **M**

Roberson, P. 1995. New River ranks as threatened waterway. Sates News Service, 18 April 1995,

Robinson, E. 1993. Osmotic and Ionic Regulation in Two Species of Freshwater Thiarids, *Thiara* (*Tarebia*) *granifera* and *Thiara* (*Melanoides*) *tuberculata*. Senior thesis, Pomona College, Claremont CA. 36 pp. **M**

Robinson, F. E., and J. N. Luthin. 1976. Adaptation to Increasing Salinity of the Colorado River. Univ. Calif. Davis, Water Resources Center. 51 pp.

Robinson, P. T., and W. A. Elders. 1971. Late Cenozoic volcanism in the Imperial Valley, California. Geol. Soc. Amer. Abstracts, 3: 185.

Robinson, P. T., W. A. Elders, and L. P. J. Muffler. 1973. Quaternary volcanism in the Salton Sea geothermal fields, Imperial Valley. Geol. Soc. Amer. Bull. 87: 3347–3360. **M**

Robison, J. H. 1963. Preliminary Results on the Availability of Ground Water in the Imperial Valley Area. US Geol. Surv. Open-file Rep. #63–116. 41 pp.

Rocke, T. E., and P. Nol. 2000. Avian botulism in fish-eating birds at the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Rocke, T. E., and M. J. Wolcott. 1998. An environmental assessment of the Salton Sea: Survey of selected microbial pathogens in the Salton Sea. Prepared for Salton Sea Authority by US Geological Survey Biological Resources Division, Madison WI. The Salton Sea Database Program, U. of Redlands, CA.

Rockwell, T. K., and A. G. Sylvester. 1979. Neotectonics of the Salton Trough. pp. 41–52 in J. C. Crowell and A. G. Sylvester, eds. Tectonics of the Juncture between the San Andreas Fault System and the Salton Trough, Southeastern California: A Guidebook for the Annual Meeting of the Geological Society of America, San Diego CA. Univ. Calif. Santa Barbara, Dept. Geol. Sci.

Rockwood, C. R. 1909. Born of the Desert. Calexico Chronicle, Calexico CA. 44 pp. Reprinted as The Early History of Imperial County, pp. 96–153 in F. C. Farr, ed. The History of Imperial County, California. Elms and Frank, Berkeley CA. Reprinted in 1949 as Born of the Desert. pp. 1–44 by Calexico Chronicle, Calexico CA. **M**

Roessler, M. A., G. L. Beardsley, and D. C. Tabb. 1977. New records of the introduced snail, *Melanoides tuberculata* (Mollusca: Thiaridae) in south Florida. Florida Sci. 40: 87–94. **M**

Rogers, A. F. 1926a. Geology of Cormorant Island, Salton Sea, Imperial County, California. Geol. Soc. Amer. Bull. 37: 219. (abstract)

Rogers, A. F. 1926b. Geology of Cormorant Island, Salton Sea, Imperial County, California. Pan Amer. Geol. 45: 249–250. (abstract)

Rogers, A. F. 1934a. Salton volcanic domes of Imperial County, California. Pan-American Geol. 61: 372–373.

Rogers, A. F. 1934b. Salton volcanic domes of Imperial County, California. Geol. Soc. Amer. Proc. 1934: 328. (abstract)

Rogers, F. L. 1949. Three new subspecies of *Balanus amphitrite* from California. J. Entomol. Zool. 41: 23–32. **M**

Rogers, M. J. 1939. Early Lithic Industries of the Lower Basin of the Colorado River and Adjacent Desert Areas. Ballen Press, Ramona CA. 75 pp. Reprinted 1973. by San Diego Mus. San Diego CA.

Rogers, M. J. 1945. An outline of Yuman prehistory. Southwestern J. Anthropol. 1: 167–198.

Rogerson, A., and G. Hauer. 2000. Naked amoeboid protozoa of the Salton Sea, California. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Romer, M. 1922. History of Calexico. South. Calif. Hist. Soc. Ann. Publ. 12 (2): 44 pp.

Rook, S. H., and G. C. Williams. 1942. Imperial carbon dioxide gas field: summary of operations. Calif. Div. Oil Gas Bull. 28: 12–23. **M**

Room, P. M., and I. V. S. Fernando. 1992. Weed invasions countered by biological control—*Salvinia molesta* and *Eichhornia crassipes* in Sri Lanka. Aquat. Bot. 42: 99–107. **M**

Roosevelt, T. 1907. Imperial Valley or Salton Sink Region: Message from the President—Relative to the Threatened Destruction by the Overflow of the Colorado River in the Sink or Depression known as the Imperial Valley or Salton Sink Region. Address to US Senate. US Gov. Printing Office. Reprinted in de Stanley, M. 1976. The Salton Sea Yesterday and Today. Triumph Press, Los Angeles, CA.

Rosen, M. D. 1984. First Supplemental Historic Property Survey Materials Sites for Imperial 86 Expressway. Report on file at Environmental Analysis Branch "B", Caltrans District 11, San Diego CA.

Rosen, M. D. 1987. Fifth Addendum Archaeological Survey Report for Units 4 and 5 of the Proposed State Route 86 Expressway. Report on file at the Environmental Analysis Branch, Caltrans District 11, San Diego CA.

Rosen, M. D. 1989. Archaeological Survey Report for the New River Gravel Bar Material Site. Report on file at the Environmental Analysis Branch, Caltrans District 11, San Diego CA.

Rosen, M. D. 1994. Analysis of shell beads, ornaments, and unmodified shell fragments from CA-IMP-6427, Imperial County, California. in D. Laylander. Phase III Data Recovery at the Elmore Site (CA-IMP-6427), Imperial County, California. Caltrans, District 11, San Diego CA.

Rosen, M. D. 1995. IMP-6427, a Lake Cahuilla shell bead manufacturing site. Soc. Calif. Archaeol. Proc. 8: 87–104.

Rosenberg, K. V., R. D. Ohmart, W. C. Hunter, and B. W. Anderson. 1991. Birds of the Lower Rio Colorado Valley. Univ. Arizona Press, Tucson AZ. 416 pp.

Ross, W. H. 1914. Chemical composition of the water of Salton Sea and its annual variation in concentration, 1906–1911. pp. 35–46 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L.

Ross, W. H. 1915. The chemical composition of the water of Salton Sea and its annual variation in concentration. pp. 37–41 in H. T. Cory, ed. The Imperial Valley and the Salton Sink. J. J. Newbegin, San Francisco.

Rowlands, P. G. 1995a. Regional bioclimatology of the California desert. pp. 95–134 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA. **M**

Rowlands, P. G. 1995b. Vegetational attributes of the California Desert Conservation Area. pp. 135–183 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA. **M**

Rowlands, P. G. 1995c. Vegetation dynamics of the California Desert Conservation Area. pp. 185–211 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Rubega, M. A., and J. A. Robinson. 1997. Water salinization and shorebirds: emerging issues. International Wader Studies 9: 45–54.

Ruibal, R. 1959. The ecology of a brackish water population of *Rana pipiens*. Copeia 1959: 315–322. **M**

Ruibal, R. 1963. The ecology and genetics of a desert population of *Rana pipiens*. Copeia 1963: 189–195. **M**

Ruiz, M. D. H. 2000. Water reserves in the El Pinacate and Gran Desierto de Altar biosphere, Sonora, Mexico: communities, wildlife, and the border with the United States. Natural Resources J. 40: 411–434.

Russo, T. N. 1974. Discovery of the gastropod snail *Melanoides tuberculata* (Müller) new record in Florida. Florida Sci. 36: 212–213. **M**

Rust, H. H. 1891. The desert sea. Calif. Illustr. Mag. 1 (1): 94–102. **M**

Rymer, M. J. 1991. Geological structure, transpression, and neotectonics of the San Andreas Fault in the Salton Trough, California. Part 2. The Bishop Ash Bed in the Mecca Hills. Geological Excursions in the Southern California Area, Geol. Soc. Amer. Guidebook 1991. Reprinted as pp. 247–255 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA. **M**

Rymer, M. J. 1994. Quaternary fault-normal thrusting in the northwestern Mecca Hills, southern California. Geological Investigations of an Active Margin. Geol. Soc. Amer. Cordilleran Sect. Guidebook. Reprinted as pp. 268–272 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Rymer, M. J. 2000. Triggered surface slips in the Coachella Valley area associated with the 1992 Joshua Tree and Landers, California earthquakes. Seismol. Soc. Amer. Bull. 90: 832–848. **M**

Rymer, M. J., A. M. Sarna-Wojcicki, C. L. Powell, II, and J. A. Barron. 1994. Stratigraphic evidence for late Miocene opening of the Salton Trough in southern California. Cordilleran Sect., Geol. Soc. Amer. 26(2): 87.

Saiki, M. K. 1990. Elemental concentrations in fishes from the Salton Sea, southeastern California. Water Air Soil Pollut. 52: 41–56. (abstract) **M**

Saint, P. K. 1976. Geothermal Guide to Mexicali-Imperial Valley Rift Valley. Geothermal Energy Assoc. West Covina CA.

Salmen, C. 1982. Aquatic invertebrates. pp. 95–104 in A. Lebo, L. Nitikman, and C. Salmen. San Sebastian Marsh: A Resource Survey and Management Plan, Imperial County, California. Publication #9, Environmental Field Program, Univ. Calif. Santa Cruz.

Salton Sea Authority and US Bureau of Reclamation. 1994. Proc. Salton Sea Symposium, 13 January 1994. Indian Wells CA.

Salton Sea Authority and US Bureau of Reclamation. 1998. The Salton Sea: A Brief Description of its Current Condition and Potential Remediation Projects. Salton Sea Authority and US Bur. Reclam. Indio CA. 22 January 1998.

Salton Sea Authority and US Bureau of Reclamation. 1999. Administrative Draft: Salton Sea Restoration Project Environmental Impact Statement/Environmental Impact Report. La Quinta, CA and Boulder City, Nevada. **M**

Salton Sea Authority and US Bureau of Reclamation. 2000a. Salton Sea Restoration Project. Draft Alternatives Appraisal Report and Environmental Impact Statement/Environmental Impact Report. Prepared for Salton Sea Authority and US Bureau of Reclamation by Tetra Tech Inc. 2 vols. Variously paginated. **M**

Salton Sea Authority and US Bureau of Reclamation. 2000b. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. **M**

Samadi, S., E. Artiguebielle, A. Estoup, J.-P. Pointier, J. F. Silvain, J. Heller, M. L. Cariou, and P. Jarne. 1998. Density and variability of dinucleotide microsatellites in the parthenogenetic polyploid snail *Melanoides tuberculata.* Molec. Ecol. 7: 1233–1236. **M**

Samadi, S., J. Mavarez, J.-P. Pointier, B. Delay, and P. Jarne. 1999. Microsatellite and morphological analysis of population structure in the parthenogenetic freshwater snail *Melanoides tuberculata*: insights into the creation of clonal variability. Molec. Ecol. 8: 1141–1153. **M**

Samadi, S., P. David, and P. Jarne. 2000. Variation of shell shapes in the clonal snail *Melanoides tuberculata* and its consequences for the interpretation of fossil series. Evolution, 34: 492–502.

Sanguinetti, M. C. 1980. Osmoregulation and ionic balance in *Trichocorixa reticulata* (Guérin-Menéville). Comp. Biochem. Physiol. 65A: 477–482. **M**

Santolo, G. M., and J. T. Yamamoto. 1999. Selenium in blood of predatory birds from Kesterson Reservoir and other areas in California. J. Wildlife Manag. 63: 1273–1281.

Sass, J. H. 1986. Salton Sea Scientific Drilling Project: On-site Management 1986. US Geol. Surv. Open-file Rep. 86–397. 1 vol.

Sass, J. H. 1988. Salton Sea Scientific Drilling Program. Earthquakes and Volcanoes 20: 156–160.

Savage, A. A. 1980. The Gammaridae and Corixidae of an inland saline lake from 1975 to 1978. Hydrobiologia 76: 33–44.

Savage, J. C., M. K. Lisowski, N. E. King, and W. K. Gross. 1994. Strain accumulation along the Laguna Salada Fault, Baja California, Mexico. J. Geophys. Res.-Solid Earth 99: 18109–18116.

Schackley, M. S. 1981. Late Prehistoric Exchange Network Analysis in Carrizo Gorge and the Far Southwest. Coyote Press, Salinas CA.

Schaefer, J. 1986. Late Prehistoric Adaptations During the Final Recessions of Lake Cahuilla: Fish Camps and Quarries on West Mesa, Imperial County, California. Report prepared by Mooney-LeVine and Associates for the US Bureau Land Manag. El Centro Resource Area, El Centro CA.

Schaefer, J. 1988. Lowland Patayan Adaptations of Ephemeral Alkali Pans at Superstition Mountain, West Mesa, Imperial County, California. Report prepared by Brian F. Mooney Associates for US Bureau Land Manag. El Centro CA.

Schaefer, J. 1993. Archaeological Investigations of Two Lake Cahuilla Sites in the Toro Canyon Area Riverside County, California. Report prepared by Brian F. Mooney Associates for George Berkey and Associates, Inc., Palm Desert CA.

Schaefer, J. 1994a. The challenge of archaeological research in the Colorado Desert: recent approaches and discoveries. J. Calif. Great Basin Anthropol. 16: 60–80.

Schaefer, J. 1994b. The stuff of creation: recent approaches to ceramics analysis in the Colorado Desert. pp. 81–100 in J. A. Ezzo, ed. Recent Research Along the Lower Colorado River. Statistical Research Technical Series #51, Tucson AZ.

Schaefer, J. 1995. Ceramics. pp. 1–73. in L. J. Bean, J. Schaefer, and S. B. Vane, eds. Archaeological, Ethnographic, and Ethnohistoric Investigations at Tahquitz Canyon, Palm Springs, California. Prepared by Cultural Systems Research, Inc. for Riverside County Flood Control and Water Conservation District, Riverside CA.

Schaefer, J. 1998. A Treatment Plan and Research Design for Cultural Resources of the Imperial Irrigation District's L-line Pole Replacement Project, Imperial and Riverside Counties, California. Report by ASM Affiliates for the Imperial Irrigation District, Imperial CA. 56 pp. **M**

Schaefer, J. 1999. Pit and Mortuary Features at a Protohistoric Lake Cahuilla Temporary Camp: Results of Supplementary Phase III Data Recovery at the Elmore Site (CA-IMP-6427). Report prepared by ASM Affiliates for Caltrans, District 11, San Diego CA.

Schaefer, J. 2000. Archaeological Investigations at a Protohistoric Fish Camp on the Receding Shoreline of Ancient Lake Cahuilla, Imperial County, California. Report by ASM Affiliates for the Imperial Irrigation District, Imperial CA.

Schaefer, J., L. J. Bean, and C. M. Elling. 1987. Settlement and Subsistence at San Sebastian, a Desert Oasis on San Felipe Creek, Imperial County, California. Report prepared by Brian F. Mooney Associates for the US Bureau Reclam., Boulder City NV.

Schaefer, J., D. Pallette, and C. O'Neill. 1998. A Cultural Resources Inventory and Evaluation of the Imperial Irrigation District's L-line Pole Replacement Project Imperial and Riverside Counties, California. Report by ASM Affiliates for the Imperial Irrigation District, Imperial CA.

Schlegel, L., J.-P. Pointier, V. Petitjean Roget, Y. Nadeau, A. Blateau, and J. M. Mansuy. 1997. The control of intestinal schistosomiasis from Martinique Island. Parasite-J. Soc. Franc. Parasit. 4: 217–225.

Schler, C. A., R. G. Anthony, and H. M. Ohlendorf. 1990. Selenium in wetlands and waterfowl foods at Kesterson Reservoir, California. Arch. Environ. Contam. Toxicol. 19: 845–853.

Schlosser, H. J., and K. Anger. 1982. The significance of some methodological effects on filtration and ingestion rates of the rotifer *Brachionus plicatilis.* Helgo. Wiss. Meeresunters. 35: 215–225.

Schoenherr, A. A. 1979. Niche separation within a population of freshwater fishes in an irrigation drain near the Salton Sea, California. South. Calif. Acad. Sci. Bull. 78: 46–55. **M**

Schoenherr, A. A. 1981. The role of competition in the replacement of native fishes by introduced species. pp. 173–203 in R. J. Naiman and D. L. Soltz, eds. Fishes in North American Deserts. Wiley-Interscience, New York City NY. **M**

Schoenherr, A. A. 1988. A review of the life history and status of the desert pupfish. South. Acad. Sci. Bull. 87: 104–134. **M**

Schoenherr, A. A. 1993a. A Natural History of California. Univ. Calif. Press, Berkeley CA. 772 pp. **M**

Schoenherr, A. A. 1993b. Rise and fall of the desert pupfish, *Cyprinodon macularius,* at the Salton Sea. pp. 67–68 in R. E. Reynolds and J. Reynolds, eds. Ashes, Faults and Basins. The 1993

Mojave Desert Quaternary Research Center Field Trip. San Bernardino County Mus. Assoc. Sp. Publ. 93–1. **M**

Schoenherr, A. A., and C. R. Feldmeth. 1993. Thermal tolerances for relict populations of desert pupfish, *Cyprinodon macularius.* San Bernardino County Mus. Assoc. Quart. 40 (2): 32–33. **M**

Schonfeld, R. G. 1969. The early development of California's Imperial Valley. South. Calif. Quart. September/December 1968: 279–307.

Schroeder, R. A. 1996. Transferability of environmental assessments in the Salton Sea Basin, California, and other irrigated areas in the western United States to the Aral Sea Basin, Uzbekistan. pp. 121–137 in P. P. Minklin, and W. D. Williams, eds. The Aral Sea Basin. NATO Adv. Sci. Inst. Ser., Partnership Subser. 2, vol. 12. Springer-Verlag, Berlin, Germany.

Schroeder, R. A., and W. H. Orem. 2000. Nutrient dynamics in the Salton Sea—implications from calcium, uranium, molybdenum and selenium. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Schroeder, R. A., J. G. Setmire, and J. C. Wolfe. 1988. Trace elements and pesticides in the Salton Sea area of California. pp. 700–707 in Planning Now for Irrigation and Drainage. Proc. Amer. Soc. Engineers, Irrigation Drainage Div., Lincoln NB 19–21 July 1988.

Schroeder, R. A., J. G. Setmire, and J. N. Densmore. 1989a. Controls on drainwater composition in the Imperial Valley, California. in US Geol. Surv. Water Resources Div. National Symp. Water Quality. US Geol. Surv. Open File Rep. 93–83.

Schroeder, R. A., J. G. Setmire, and J. N. Densmore. 1989b. Controls on drainwater composition in Imperial Valley, California. p. 85 in G. L. Pederson, and M. M. Smith, compilers. US Geological Survey Second National Symposium on Water Quality: Abstracts of the Technical Sessions. Orlando FL, 12–17 November 1989. US Geol. Surv. Open-file Rep. 89–409.

Schroeder, R. A., J. G. Setmire, and J. N. Densmore. 1991. Use of stable isotopes, tritium, soluble salts, and redox-sensitive elements to distinguish groundwater from irrigation water in the Salton Sea basin. pp. 524–530 in W. F. Ritter, ed. Proc. National Conf. Amer. Soc. Civil Engineers, Irrigation Drainage Div., Lincoln NB.

Schroeder, R. A., M. Rivera, J. B. Redfield, J. N. Densmore, R. L. Michel, D. R. Norton, D. J. Audet, J. G. Setmire, and S. L. Goodbred. 1993. Physical, Chemical, and Biological Data for Detailed Study of Irrigation Drainage in the Salton Sea area, California, 1988–90. US Geol. Surv. Open-file Rep. 93–83. 179 pp.

Schultejann, P. A. 1984. The Yaqui Ridge antiform and detachment fault: mid-Cenozoic extensional terrane west of the San Andreas Fault. Tectonics, 3: 677–691.

Schulze-Wiehenbrauck, H. 1977/78. Influence of water-soluble excreta on oxygen consumption of *Tilapia zillii.* Meeresforschung, 26: 131–136.

Scientific Committee on Problems of the Environment Working Group on Man-made lakes. 1972. Man-made Lakes as Modified Ecosystems. International Council Scientific Unions, Paris, France, SCOPE Rep. #3. 76 pp.

Scientists of the US Geological Survey, Southern California Earthquake Center, and California Division of Mines and Geology. 2000. Preliminary report on the 16 October 1999 M 7.1 Hector Mine, California, earthquake. Seismol. Res. Let. 71: 11–23. **M**

Seckler, D., ed. 1971. California Water: a Study in Resource Management. Univ. Calif. Press, Berkeley CA. 348 pp.

Seddon, M. 1982. What Ever Happened to the Chocolate Mountain Gang? Events Involving Early Campers at Imperial County Original Old Spa. Sun Graphics, Yuma AZ. 71 pp.

Segers, H. 1995. Nomenclatural consequences of some recent studies on *Brachionus plicatilis* (Rotifera, Brachionidae). Hydrobiologia 313: 121–122. **M**

Segerstråle, S. G. 1957. Baltic Sea. Geol. Soc. Amer. Mem. 67: 751–800. **M**

Serra, M., A. Gómez, and M. J. Carmona. 1998. Ecological genetics of *Brachionus plicatilis* sibling species. Hydrobiologia 387:373–384. **M**

Setmire, J. G. 1979. Water-quality conditions in the New River, Imperial County, California. US Geol. Surv. Water-Resources Invest. Rep. 79–86. 63 pp.

Setmire, J. G. 1984. Water quality in the New River from Calexico to the Salton Sea, Imperial County, California. US Geol. Surv. Water-supply Pap. 2212: 42 pp.

Setmire, J. G. 2000. Contaminants in the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Setmire, J. G., and R. Schroeder, 1998. Selenium and salinity concerns in the Salton Sea area of

California. pp. 205–221 in W. T. Frankenberger, Jr., and R. A. Engberd, eds. Environmental Chemistry of Selenium. Marcel Dekker, New York City NY. **M**

Setmire, J. G., J. C. Wolfe, and R. K. Stroud. 1990. Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Salton Sea Area, California, 1986–87. US Geol. Surv. Water-Invest. Rep. 89–4102. 68 pp. **M**

Setmire, J. G., R. Schroeder, J. N. Densmore, S. L. Goodbred, D. J. Audet, and W. R. Radke. 1993. Detailed Study of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Salton Sea Area, California, 1988 to 1989. US Geol. Surv. Open-file Rep. 93–4014. 102 pp. **M**

Sharp, R. P. 1964. Wind-driven sand in Coachella Valley. Geol. Soc. Amer. Bull. 75: 785–804.

Sharp, R. P. 1978. Geological aspects of the eastern Mojave Desert and Salton Trough. pp. 1–7 in R. Greeley, ed. Aeolian Features of Southern California: A Comparative Planetary Geology Guidebook. National Aeronaut. Space Admin. Washington DC.

Sharp, R. V. 1972. Tectonic setting of the Salton Trough. pp. 3–15 in The Borrego Mountain Earthquake of April 9, 1968. US Geol. Surv. Prof. Pap. 787.

Sharp, R. V. 1982. Tectonic setting of the Imperial Valley region. pp. 5–14 in The Imperial Valley, California, Earthquake of October 15, 1979. US Geol. Surv. Prof. Pap. 1254.

Sharp, R. V., and G. C. Cork. 1995. Geology and mining of the Miocene Fish Creek Gypsum in Imperial County, California. pp. 169–180 in M. Tabilio and D. S. Dupras, eds. Proc. 29th Forum on the Geology of Industrial Minerals. Calif. Dept. Conserv. Div. Mines Geol. Sp. Publ. 110.

Sharp, R. V., J. J. Lienkaemper, M. G. Bonilla, D. B. Burke, B. F. Fox, D. G. Herd, D. M. Miller, D. M. Morton, D. J. Ponti, M. J. Rymer, J. C. Tinsley, J. C. Yount, J. E. Kale, E. W. Hart, and K. E. Sieh. 1982. Surface faulting in the central Imperial Valley. pp. 119–143 in The Imperial Valley, California, Earthquake of October 15, 1979. US Geol. Surv. Prof. Pap. 1254.

Sheehan, J. R. 1986. A tectonic model of the Salton Trough. pp. 165–172 in P. G. Guptill, R. W. Ruff, and E. M. Grath, eds. Geology of the Imperial Valley, California. South Coast Geol. Soc. Guidebook #14, Santa Ana CA.

Sheehan, J. R. 1988. Tectonic model of the Salton Trough. pp. 7–14 in S. M. Testa and K. E. Green, eds. Geologic Field Guide to the Western Salton Basin Area. Amer. Inst. Prof. Geol. Calif. Sect.

Sheldon, F., and K. F. Walker. 1997. Changes in biofilms induced by flow regulation could explain extinctions of aquatic snails in the lower River Murray, Australia. Hydrobiologia 347: 97–108.

Shelton, C. E. 1963, A guide to the Coachella Valley. Desert Mag. March 1963: 28–36.

Shelton, J. S. 1966. Geology Illustrated. W. H. Freeman, San Francisco CA. 434 pp.

Shepherd, F. J. 1934. A Bibliography of the Historical, Scientific and Engineering Literature Relating to the Imperial Valley and Vicinity and the Lower Colorado River. Central Junior College, El Centro CA. 332 pp.

Sherer, C. K., J. J. Papike, S. B. Simons, B. L. Davis, and J. C. Laui. 1988. Mineral reactions in altered sediments from the California State 2–14 well: variations in the model mineralogy, mineral chemistry and bulk composition of the Salton Sea Scientific Drilling Project core. pp. 13, 104–113, 122 in W. A. Elders, ed. A Compendium of Reports on the Salton Sea Scientific Drilling Project. Center Geothermal Res., Inst. Geophys. Planetary Physics, Univ. Calif. Riverside.

Sheridan, D. 1981. The desert blooms—at a price. Environment, 23 (3): 6–24, 38–41. **M**

Sheridan, J. M., and R. J. Weldon II. 1994. Accommodation of compression in the Mecca Hills, California. Geol. Soc. Amer. Cordilleran Sect. Guidebook 1994. Reprinted as pp. 273–279 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Sheridan, J. M., R. J. Weldon II, C. A. Thornton, and M. J. Rymer. 1994. Stratigraphy and deformational history of the Mecca Hills, southern California. Geological Investigations of an Active Margin. Geol. Soc. Amer. Cordillera Section, Guidebook 1994. Reprinted as pp. 262–268. in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Shiba, H., H. Yamamoto, and K. Horikoshi. 1989. Isolation of strictly anaerobic halophiles from the

aerobic surface sediments of hypersaline environments in California and Nevada. (Fed. Eur. Microbiol. Soc.) Microbiol. Lett. 57: 191–196.

Shields, E. F. 1972. Coachella Valley Desert Trails: the Salton Sea Saga, and the Romance and Sex Life of the Date. 10th ed. Shield's Date Gardens, Indio CA. 39 pp.

Shifflett, H., E. Ambose, R. Grannell, M. Gray, and L. McBee. 1997. Pleistocene to Holocene behavior of the southern San Andreas fault. pp. 288–299 in: J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Shinn, J. H., ed. 1976. Potential Effects of Geothermal Energy Conversion on Imperial Valley Ecosystems. Univ. Calif. Lawrence Livermore National Laboratory, UCRL-52196. 77 pp. **M**

Shipek, F. 1981. A native American adaptation to drought: The Kumeyaay as seen in the San Diego Mission records. Ethnohistory, 28: 295–312.

Shipek, F. 1982. The Kamia (Desert or Eastern Kumeyaay). pp. 21–33 in C. Woods, ed. APS/SDG&E Interconnection Project: Native American Cultural Resources. Wirth Assoc. San Diego CA

Shipek, F. 1985. Kuuchamaa: the Kumayaay sacred mountain. J. Calif. Great Basin Anthropol. 7: 67–74.

Shipek, F. 1989. An example of intensive plant husbandry: the Kumeyaay of southern California. pp. 159–170 in D. R. Harris and G. C. Hillman, eds. Foraging and Farming: the Evolution of Plant Exploitation. Onwin Hyman, London UK.

Shipek, F. 1991. Delfina Cuero: her Autobiography, an Account of her Last Years and her Ethnobotanic Contributions. Ballena Press Anthropol. Papers #37.

Shiroma, L. 1990. On Birthrate and Production of *Thiara granifera* in Varying Salinities. Senior thesis, Pomona College, Claremont CA. 26 pp. **M**

Shrake, C. A. 1991. A Landscape Ecology Analysis for the New and Alamo Rivers of the Mexicali-Imperial Rift Valley. Ph.D. dissertation, Univ. Calif. Los Angeles. 297 pp.

Shuford, W. D., G. W. Page, and C. M. Hickey. 1995. Distribution and abundance of snowy plovers wintering in the interior of California and adjacent states. Western Birds, 26: 82–98.

Shuford, W. D., G. W. Page, and J. Knelmyr. 1998. Patterns and dynamics of shorebird use of California's Central Valley. Condor 100: 227–244.

Shuford, W. D., N. Warnock, and K. C. Molina. 1999. The avifauna of the Salton Sea: a synthesis. Prepared for the Salton Sea Authority by the Point Reyes Bird Observatory. Salton Sea Database Program, U. of Redlands, CA. ⟨www.institute.redlands.edu/salton/recon/index.aspx⟩**M**

Shumway, N. 1979. Your Desert and Mine. ETC Publ., Palm Springs CA. 336 pp.

Sieh, K., and P. L. Williams. 1990. Behavior of the southernmost San Andreas Fault during the past 300 years. J. Geophys. Res. 95: 6629–6645. Reprinted as pp. 332–348 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA. **M**

Silver, P. A., and J. N. Valette-Silver. 1987. A spreading episode at the southern end of the San Andreas fault system. Nature 326: 589–593.

Simila, G., H. Adams, and G. Roquemore. 1997. Seismicity of the San Andreas Fault zone: White Water [*sic*] Canyon to Bombay Bay [*sic*], 1987–1997. p. 187 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA.

Simmons, E. G. 1957. An ecological survey of the upper Laguna Madre. Publ. Inst. Mar. Sci., Port Aransas TX. 4: 156–200. **M**

Simpson, E. P. 1994. Salinity and Fish Effects on the Salton Sea Benthos. MS thesis, San Diego State Univ., San Diego CA. 116 pp.

Simpson, E. P., and S. H. Hurlbert. 1998. Salinity effects on growth, mortality and shell strength of *Balanus amphitrite* from the Salton Sea, California. Hydrobiologia 381: 179–190. **M**

Simpson, E. P., M. R. González, C. M. Hart, and S. H. Hurlbert. 1998. Salinity and fish effects on Salton Sea microecosystems: benthos. Hydrobiologia, 381 153–177. **M**

Sixtus, M. E. 1978. Aspects of the Physiology and Biochemistry of Thermal Adaptation in Two Populations of Barnacles (*Balanus amphitrite* Darwin). MS thesis, San Diego State Univ. San Diego CA. 78 pp. (abstract) **M**

Skinner, B. J., D. E. White, H. J. Rose, and R. E. Mays. 1967. Sulfides associated with the Salton Sea geothermal brine. Econom. Geol. 62: 316–330.

Skrove, T. 1986. The Salton Sea: nature's accident in the desert. Aqueduct (Metropolitan Water District), 52 (4): 9–13. **M**

Slack, G. 1997. Salton Sea sickness. Pacific Discovery, Winter 1997.

Slootweg, R., E. A. Malek, and F. S. McCullough. 1994. The biological-control of snail intermediate hosts of schistosomiasis by fish. Rev. Fish. Biol. Fisher. 4: 67–90.

Small, A. 1994. Birds of California: Their Status and Distribution. Ibis Publ. Co., Vista CA. 342 pp. **M**

Small, E. B., and G. F. Gebler. 2000. Ciliate diversity in the Salton Sea, California. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Smith, D. M. 1942. The Effect of the Desiccation of Ancient Lake Cahuilla upon the Culture and Distribution of some of the Desert Indians of Southern California. MA thesis, Univ. South. Calif., Los Angeles CA. 144 pp.

Smith, R. I. 1958. On reproductive pattern as a specific characteristic among nereid polychaetes. Syst. Zool. 7: 60–73. **M**

Snell, T. W., and C. A. Hawkinson. 1983. Behavioral reproductive isolation among populations of the rotifer *Brachionus plicatilis*. Evolution 37: 1294–1305.

Snoeberger, D. F., J. H. Hill, and H. Brandt. 1978. Identification of Environmental Control Technologies for Geothermal Development in the Imperial Valley of California. Univ. Calif. Lawrence Livermore National Lab., UCRL-52548: 30 pp.

Somero, G. N., T. J. Chow, P. H. Yancey, and C. B. Snyder. 1977a. Lead accumulation rates in tissues of the estuarine teleost fish, *Gillichthys mirabilis*: salinity and temperature effects. Arch. Environ. Contam. Toxicol. 6: 337–348.

Somero, G. N., P. H. Yancey, T. J. Chow, and C. B. Snyder. 1977b. Lead in tissue and whole organism respiration of the estuarine teleost fish, *Gillichthys mirabilis*. Arch. Environ. Contam. Toxicol. 6: 349–354.

Sonny Bono Salton Sea National Wildlife Refuge. 1999. 1999 Fish and Wildlife Mortality Events. US Fish Wildlife Serv. Sonny Bono Salton Sea National Wildlife Refuge. ⟨pacific.fws.gov/salton⟩

Sonny Bono Salton Sea National Wildlife Refuge. 2000a. Mortality roster 2000. US Fish Wildlife Serv. Sonny Bono Salton Sea National Wildlife Refuge. ⟨pacific.fws.gov/salton⟩

Sonny Bono Salton Sea National Wildlife Refuge. 2000b. Endangered brown pelicans dying at Salton Sea: Avian botulism outbreaks may claim more birds than 1996 epidemic. US Fish Wildlife Serv. Sonny Bono Salton Sea National Wildlife Refuge.

Soske, J. L., and V. C. Kelley. 1935. Wave-built pumice deposits and Salton rhyolite hills. Pan-Pacific Geologist, 63: 319–320.

Soulé, J. D. 1957. Two species of Bryozoa Ctenostomata from the Salton Sea. South. Calif. Acad. Sci. Bull. 56: 21–30.

South Coast Air Quality Management District. 1990. Draft Environmental Impact Report, Draft 1990 State Implementation Plan for PM10 in the Coachella Valley. South Coast Air Qual. Manage. Dist., El Monte CA.

South Coast Air Quality Management District. 1997. Final 1997 Air Quality Management Plan. South Coast Air Qual. Manag. Dist., El Monte CA.

Spencer, J. E., and P. J. Patchett. 1997. Sr isotope evidence for a lacustrine origin for the upper Miocene to Pliocene Bouse Formation, lower Colorado River trough, and implications for timing of Colorado Plateau uplift. Geol. Soc. Amer. Bull. 109: 767–778.

Spier, L. 1923. Southern Diegueño Customs. Univ. Calif. Publ. American Archaeol. Ethnol. 20: 292–358.

Spier, L. 1933. Yuman Tribes of the Gila River. Univ. Chicago Press, Chicago IL.

St. Amant, J. A. 1966. Addition of *Tilapia mossambica* Peters to the California fauna. Calif. Fish Game, 52: 54–55. **M**

St. Amant, J. A., and J. S. Day. 1972. Range extensions of *Palaemonetes paludosus* (Gibbes) in California. Calif. Fish Game, 58: 154–155. **M**

St. Amant, J. A., and I. Sharp. 1971. Addition of *Xiphophorus variatus* (Meek) to the California fish fauna. Calif. Fish Game, 57: 128–129. **M**

St. Amant, J. A., G. F. Black, R. Hulquist, A. Pickard, R. L. Young, and G. Seymour. 1978. The Salton Sea: fishing the great inland sea. Outdoor Calif. 1978 (July/August): 13–22. **M**

Stanley, N. F., and M. P. Alpers, eds. 1975. Man-made Lakes and Human Health. Academic Press, New York City NY. 495 pp.

Stearns, N. D., H. J. Stearns, and G. A. Waring. 1937. Thermal springs in the United States. US Geol. Surv. Water-supply Pap. 679-B: 1–206.

Stearns, R. E. C. 1902. The fossil freshwater shells of the Colorado Desert, their distribution, environment, and variation. US National Mus. Proc. 24: 271–299. **M**

Stebbins, R. C. 1985. A Field Guide to Western Reptiles and Amphibians. 2nd ed., revised. Houghton Mifflin, Boston. 336 pp. **M**

Stebbins, R. C., and J. Latting. 1995. A review of BLM management prescriptions for offroad vehicle recreational use in the California Desert Conservation Area. pp. 593–627 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Steere, C. H. 1953. Imperial and Coachella Valleys. Revised ed. Stanford Univ. Press, Stanford CA. 86 pp.

Stein, J. 1978. New River: a sewer from Mexico. Washington Post, 11 December 1978.

Stene, E. A. 1995. The All-America Canal System: Boulder Canyon Project. US Bureau of Reclamation History Program, Denver CO. 53 pp.

Stephen, M. F., and G. R. Gorsline. 1975. Sedimentary aspects of the New River delta, Salton Sea, Imperial County, California. pp. 267–282 in M. L. Broussard, ed. Deltas: Models for Exploration. Houston Geol. Soc., Houston TX.

Stephens, D. W. 1990. Changes in lake levels, salinity and the biological community of Great Salt Lake (Utah, US A.), 1847–1987. pp. 139–144 in F. Comin, and T. Northcote, eds. Saline Lakes IV. Kluwer Acad. Publ., Boston MA.

Stephens, D. W. 1998. Salinity-induced changes in the aquatic ecosystem of Great Salt Lake, Utah. pp. 1–7 in J. Pitman, and A. Carroll, eds. Modern and Ancient Lake Systems. Utah Geol. Surv. Guidebook 26.

Sterrenburg, F. A. S., M. A. Tiffany, and C. B. Lange. 2000. Studies on the genera *Gyrosigma* and *Pleurosigma* (Bacillariophyceae)—species from the Salton Sea, California, USA, including *Pleurosigma ambrosianum,* nov. sp. Acad. Natural Sci. Philadelphia, Proc. 150: 305–313. **M**

Stewart, K. M. 1986. Mohave. pp. 55–70 in A. Ortiz, ed. Handbook of North American Indians, Vol. 10, Southwest. Smithsonian Inst. Press Washington DC.

Stewart, M. A., and A. E. Stewart, eds. 1989. Niland Sketch Book and Historical Notes of the Northern Garden Empire of the Imperial Valley, California. Talking Leaves Press. 50 pp.

Stoddart, J. A. 1983. The accumulation of genetic variation in a parthenogenetic snail. Evolution, 37: 546–554. **M**

Stoddart, J. A. 1985. Analysis of species lineages of some Australian thiarids (Thiaridae, Prosobranchia, Gastropoda) using the evolutionary species concept. J. Malacol. Soc. Australia, 7: 1–16. **M**

Stone, R. 1999. Coming to grips with the Aral Sea's grim legacy. Science 284: 30–32. **M**

Stoyanow, V. 1964. The Abominable Sandman of Borrego. Desert Mag. 27 (July): 9–10, 31.

Strand, C. L. 1980. Mud volcanoes, faults and earthquakes of the Colorado Delta before the twentieth century. J. San Diego Hist. (San Diego Hist. Soc.) 27: 43–63.

Strong, W. D. 1929. Aboriginal Society in Southern California. Univ. Calif. Publ. Amer. Archaeol. Ethnol. 26: 1–358. **M**

Stroud, R. H., and R. M. Jenkins. 1960. Salton Sea reef. Sport Fishing Inst. Bull. 100: 5. **M**

Stuart, G. 1961. When the Sands of the Desert Grew Gold. Ye Olde Hobby Shop, Pacific Palisades CA. 204 pp.

Sturm, R., D. Stow, and T. Rockwell. 1996. Mapping Pleistocene-age shoreline deposits in the seismically-active Salton Trough using thermal infrared multi-spectral scanner (TIMS) data. Internat. J. Remote Sens. 17: 553–575.

Sturrock, A. M., Jr. 1977. Evaporation and radiation measurements at Salton Sea, California. US Geol. Surv. Open-file Rep. 77–74. 42 pp.

Sturz, A. A. 1989. Low-temperature hydrothermal alteration in near-surface sediments, Salton Sea geothermal area. J. Geophys. Res. 94: 4015–4024.

Sturz, A. A., M. Itoh, P. Earley, and M. Otero. 1997. Mud volcanoes and mud pots, Salton Sea geothermal area, Imperial Valley, California. in Deen, Metzler, and Trujillo, eds. 1997. Geology and Paleontology of the Anza-Borrego Region, California. National Assoc. Geosci. Teachers

Far Western Sect., Field Trip Guidebook. Reprinted as pp. 300–316 in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997. Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA. **M**

Sturz, A. A., D. German, and D. Putnam. 1998. Salton Sea geothermal area mud pots: 1991–1998. pp. 109–128 in L. Lindsay and W. G. Hample, eds. Geology and Geothermal Resources of the Imperial and Mexicali Valleys. San Diego Assoc. Geol. Ann. Field Trip Guide. San Diego CA. **M**

Sutton, M. Q. 1993. Midden and coprolite derived subsistence evidence: an analysis of data from the La Quinta Site, Salton Basin, California. J. Ethnobiol. 13: 1–15.

Sutton, R. 1999. The desert pupfish of the Salton Sea: a synthesis report to the Salton Sea Science Subcommittee. Prepared for Salton Sea Authority by US Bureau of Reclamation Ecological Planning and Assessment Group. Salton Sea Database Program, U. of Redlands, CA 12 pp. ⟨www.institute.redlands.edu/Salton/recon/index.aspx⟩

Sutton, R. 2000. Salton Sea desert pupfish movement study. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The Oceans: Their Physics, Chemistry, and General Biology. Prentice-Hall, New York City NY. 1087 pp. **M**

Swajian, A. 1969. Identification and Evaluation of Federal, State and Local Interests in Salton Sea, California. Revised ed. Colorado River Basin Regional Water Quality Control Board. 65 pp.

Swajian, A. 1976. Study Guide for Study of Impacts of Agricultural Discharges and Operations upon Aquatic and Wildlife Resources in Irrigation Drains in the Colorado River Basin Region. California Regional Water Quality Control Board, Colorado River Basin Region. **M**

Swan, B. K., J. M. Watts, M. A. Tiffany, and S. H. Hurlbert. 2000. Thermal mixing, and oxygen regimes of the Salton Sea, 1997–1999. Salton Sea Symposium III. Salton Sea Authority and US Bureau of Reclamation. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Sweedler, A., P. Ganster, and Bennet. 1995. Energy and Environment in the California-Baja California Border Region. San Diego St. Univ. Inst. Regional Studies Calif. 179 pp.

Sweet, J. G., and O. Kinne. 1964. The effects of various temperature-salinity combinations on the body form of newly hatched *Cyprinodon macularius* (Teleostei). Helgo. Wiss. Meeresunters. 11: 49–69. **M**

Swift, C. C., T. R. Haglund, M. Ruiz, and R. N. Fisher. 1993. The status and distribution of the freshwater fishes of southern California. South. Calif. Acad. Sci. Bull. 92: 101–167. **M**

Swift, J. 1986. The response of *Thiara granifera* to salinity changes in its external environment. Research report, Pomona College, Claremont CA. 7 pp. **M**

Sykes, G. G. 1914. Geographical features of the Cahuilla Basin. pp. 13–20 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L. **M**

Sykes, G. G. 1915. Geographic features of the Cahuilla Basin. pp. 42–51 in Cory, H. T. ed. The Imperial Valley and the Salton Sink. J. J. Newbegin, San Francisco.

Sykes, G. G. 1926. The delta and estuary of the Colorado River. Geograph. Rev. 16: 232–255. **M**

Sykes, G. G. 1937. The Colorado Delta. Carnegie Inst. Washington Publ. 460. 193 pp. (and) Amer. Geograph. Soc. Sp. Publ. 19. 193 pp. **M**

Sylvester, A. G. 1988. Strike-slip faults. Geol. Soc. Amer. Bull. 100: 1666–1703. **M**

Sylvester, A. G., and R. R. Smith. 1976. Tectonic transpression and basement-controlled deformation in San Andreas Fault zone, Salton Trough, California. Amer. Assoc. Petrol. Geol. Bull. 60: 2081–2102. Reprinted as pp. 225–246. in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA. **M**

Sylvester, A. G., and R. R. Smith. 1987. Structure sections in Painted Canyon, Mecca Hills, southern California. Geol. Soc. Amer. Centennial Field Guide—Cordillera Sect., 1987: 103–108. Reprinted as pp. 256–261. in J. Baldwin, L. Lewis, M. Payne, and G. Roquemore, eds. 1997 Southern San Andreas Fault—Whitewater to Bombay Beach, Salton Trough, California. Field Trip Guidebook #25. South Coast Geol. Soc., Santa Ana CA. **M**

Sylvester, A. G., R. Bilham, M. Jackson, and S. Barrientos. 1993. Aseismic growth of Durmid Hill, southeasternmost San Andreas Fault, California. J. Geophys. Res.-Solid Earth, 98: 14233–14243. **M**

Tait, C. R. 1908. Irrigation in Imperial Valley, California: its Problems and Possibilities. US Gov. Printing Office, Washington DC. 56 pp

Tanji, K. 1986. Selenium in the San Joaquin Valley. Environment, 28 (6): 6–11, 34–39.

Tarbet, L. A., and W. H. Holman. 1944. Stratigraphy and micropaleontology of the west side of Imperial Valley, California. Amer. Assoc. Petro. Geol. Bull. 28: 1781–1782.

Taylor, D. W. 1981. Freshwater molluscs of California: a distributional checklist. Calif. Fish Game, 67: 140–163. **M**

Test, M. L. 1980. The paradoxical sea. Western Tanager (Los Angeles Audubon Society) 46 (7): 1–4.

Testa, S. M. 1996. Early geological observations of the Colorado Desert by William Phipps Blake—1853 and 1906. pp. 1–44 in P. L. Abbott and D. C. Seymour, eds. Sturzstroms and Detachment Faults, Anza-Borrego Desert State Park, California. South Coast Geol. Soc. Ann. Field Trip Guidebook 24.

Testa, S. M., and K. E. Green, eds. 1988. Geologic Field Guide to the Southwestern Salton Basin Area. Amer. Inst. Prof. Geologists, Calif. Sect. 34 pp.

Theilacker, G. H., and M. F. McMaster 1971. Mass culture of the rotifer *Brachionus plicatilis* and its evaluation as a food for larval anchovies. Mar. Biol. 10: 183–188.

Theileg, E., M. B. Warner, and R. Papson. 1978. Geological field guide to the Salton Trough. pp. 100–159 in R. Greeley, ed. Aeolian Features of Southern California: A Comparative Planetary Geology Guidebook. US National Aeronaut. Space Admin. Washington DC.

Thelander, C. G., D. C. Pearson, and G. E. Olson, eds. 1994. Life on the Edge: a Guide to California's Endangered Natural Resources: Wildlife. Hey Day Books, Berkeley CA. 550 pp. **M**

Thomas, A. P. and T. K. Rockwell. 1996. A 300- to 550-year history of slip on the Imperial fault near the US-Mexico border: missing slip at the Imperial fault bottleneck. J. Geophys. Res.-Solid Earth 101: 5987–5997.

Thomas, B. V., A. W. Knight, and K. J. Maier. 1999. Selenium bioaccumulation by the water boatman *Trichocorixa reticulata* (Guérin-Menéville). Arch. Environ. Contam. Toxicol. 36: 295–300. **M**

Thomas, H. W., and L. G. Barnes. 1993. Discoveries of fossil whales in the Imperial Formation, Riverside County, California and the northern extent of the proto-Gulf of California. pp. 34–36 in R. E. Reynolds and J. Reynolds, eds. Ashes, Faults and Basins. The 1993 Mojave Desert Quaternary Research Center Field Trip. San Bernardino County Mus. Assoc. Sp. Publ. 93–1.

Thomas, R. G. 1962. The late Pleistocene 150-foot freshwater beach line of the Salton Sea area. South. Calif. Acad. Sci. Bull. 62: 9–17.

Thompson, C. R. 1995. Air pollution effects on desert plants. pp. 481–488 in J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Thompson J. M., and R. O. Fournier. 1988. Chemistry and geothermometry of brine produced from the Salton Sea Scientific Drill Hole, Imperial Valley, California. J. Geophys. Res. 93: 12185–13173.

Thompson, R. W. 1968. Tidal Flat Sedimentation on the Colorado River Delta, Northwestern Gulf of California. Geol. Soc. Amer. Mem. 107. 133 pp.

Thompson, W. F., and H. C. Bryant. 1920. The mullet fisheries of Salton Sea. Calif. Fish Game, 6: 60–63. **M**

Thompson, W. F., and E. Higgins 1920. Investigation of the Salton Sea. Calif. Fish Game, 6: 83–84.

Threet, R. L. 1989. Field guide for Two Trips in the Imperial Valley, California: Geomorphology of the Western Salton Sink, and San Jacinto Fault Zone and Borrego Mountain Earthquake of April 16, 1978. National Assoc. Geol. Teachers Guidebook, Far Western Sect. 42 pp.

Tiffany, M. A. 2000. Studies of the skeletal development of *Hermesium adriaticum,* a flagellate from the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract). **M**

Tiffany, M. A., S. B. Barlow, V. E. Matey, and S. H. Hurlbert. 2000a. *Chattonella marina,* a potentially toxic alga in the Salton Sea, California. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Tiffany, M. A., B. K. Swan, J. Watts, and S. H. Hurlbert. 2000b. Plankton and zooplankton dynamics in the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Tones, P. I. 1977. The life cycle of *Trichocorixa verticalis interiores* Sailer (Hemiptera, Corixidae) with special reference to diapause. Freshwater Biol. 7: 31–36.

Tout, O. B., ed. 1908. Imperial Valley. Calexico Chronicle Second Ann. Mag. Ed., Calexico CA. 1321 pp.

Tout, O. B. 1931. The First Thirty Years, 1901–1931: Being an Account of the Principal Events in the History of Imperial Valley, Southern California, U. S. A., with Chapters Describing Imperial Valley as it is Today. Otis B. Tout, Publ. San Diego CA. 429 pp. Reprinted 1990 by Imperial County Hist. Soc., Imperial CA. **M**

Treganza, A. E. 1945. The "ancient stone fish traps" of the Coachella Valley, Southern California. Amer. Antiquity 10 (3): 285–294. **M**

Trewavas, R. 1983. Tilapiine fishes of the genera *Sarotherodon, Oreochromis,* and *Danakilia.* British Mus. Nat Hist. London. 583 pp.

Trexler, J. C. 1985. Variation in the degree of viviparity in the sailfin molly, *Poecilia latipinna.* Copeia 1985: 999–1004. **M**

Turner, B. J. 1983. Genic variation and differentiation of remnant natural populations of the desert pupfish, *Cyprinodon macularius.* Evolution 37: 690–700. **M**

Turner, B. J. 1984. Evolutionary genetics of artificial refugium populations of an endangered species, the desert pupfish. Copeia 1984: 364–369. **M**

Turner, J. T., and P. A. Tester. 1992. Zooplankton feeding ecology—bacterivory by metazoan micro-zooplankton. J. Exp. Mar. Biol. Ecol. 160: 149–167. **M**

Uchida, K., T. Kaneko, H. Miyazaki, S. Hasegawa, and T. Hirano. 2000. Excellent salinity tolerance of Mozambique tilapia (*Oreochromis mossambicus*): elevated chloride cell activity in the branchial and opercular epithelia of the fish adapted to concentrated seawater. Zool. Sci. 17: 149–160. **M**

Umadevi, K. and R. Madhavi. 1995. Observations on the life cycle of *Gyrosoma indica* n. sp. (Trematoda: Psilostomidae). J. Helminthol. 69: 363–366.

Unitt, P. 1978. The little blue heron in California. Western Birds, 8: 151–154. Unitt, P. 1984. The Birds of San Diego County. San Diego Soc. Natural Hist. Mem. 13: 276 pp.

US. 1998. An Act to Direct the Secretary of the Interior, Acting Through the Bureau of Reclamation, to Conduct a Feasibility Study and Construct to Reclaim the Salton Sea, and for Other Purposes (Salton Sea Reclamation Act of 1998). US Gov. Printing Office, Washington DC. 5 pp.

US. 2000. An Act to Authorize Leases for Terms not to Exceed 99 Years on Land held in Torres-Martínez Desert Cahuilla Indians and the Guideville Band of Pomo Indians Guideville Indian Reservation. Public Law 106–210.

US Army Corps of Engineers. 1989. Reconnaissance Report, Flood Control and Related Purposes: Imperial County and San Diego County Streams that Flow into the Salton Sea. US Army Corps Engineer., Los Angeles Dist. 240 pp.

US Army Corps of Engineers. no date. Warning: Potentially Dangerous Military Munitions, The Former Salton Sea Test Base, Imperial County, Calif. US Army Corps Engineer., Washington DC. 6 pp.

US Bureau of Land Management. 1982. Final Environmental Assessment CA-066-2-4 on the Potential Impacts Resulting from Leasing of the Hydrocarbon Resources at the Salton Sea, Riverside and Imperial Counties, California. US Bur. Land Manag., Calif. Desert District, Indio Resource Area Office. 113 pp. **M**

US Bureau of Land Management. 1986. San Sebastian Marsh/San Felipe Creek Management Plan. Public Review Draft. US. Bur. Land Manag., Calif. Desert District, Indio Resource Area. 49 pp. + appendices. **M**

US Bureau of Land Management. 1987. Yuma Desalting Plant Operations and Maintenance. US Bur. Land Manag. Burns Roe Serv. Corp. Oradell NJ. 11 pp.

US Bureau of Land Management. 1988a. Environmental Assessment for San Felipe Creek Fish Barrier. US Bur. Land Manag., El Centro Resource Area. 11 pp. **M**

US Bureau of Land Management. 1988b. Draft Environmental Assessment: Coachella Canal In-place Lining Prototype. US Bur. Land Manag., Lower Colorado Region.

US Bureau of Reclamation. 1990. Yuma desalting plant: a status report. US Bur. Reclam. Yuma AZ.

US Bureau of Reclamation. 1991a. All-American Canal Lining Project, Imperial County, California: Draft Environmental Impact Statement/Draft Environmental Impact Report. US Bur. Reclam., Lower Colorado Region, Boulder City NV.

US Bureau of Reclamation. 1991b. All-American Canal Lining Project, Imperial Canal, California: Engineering Appendix for Environmental Impact Statement Report. US Bur. Reclam., Denver CO.

US Bureau of Reclamation. 1993. Coachella Canal: Final Resource Management Plan Environmental Assessment and Finding of No Significant Impact. US Bur. Reclam., Lower Colorado Region, Boulder City NV.

US Bureau of Reclamation. 1994. Draft Environmental Impact Statement/Environmental Impact Report for the Coachella Canal Lining Project. US Bur. Reclam., Lower Colorado Region, Boulder City NV.

US Bureau of Reclamation. 1997. Salton Sea Area Study: Alternative Evaluation Appraisal Report: Final Draft. US Bur. Reclam., Lower Colorado Region. 221 pp.

US Bureau of Reclamation. 1998. Salton Sea Alternatives: Final Preappraisal Report. US Bur. Reclam. Lower Colorado Region. 108 pp. **M**

US Bureau of Reclamation. 1999. Environmental Assessment for removal of tamarisk at San Felipe Area of Critical Environmental Concern. US Bur. Reclam. El Centro Field Office. 7 pp.

US Bureau of Sport Fisheries and Wildlife. 1971. Salton Sea National Wildlife Refuge: Master Plan. US Bur. Sport Fisheries Wildlife. Western Region, Portland, OR. 24 pp.

US Congress 1998 Public Law 105–372 The Salton Sea Reclamation Act of 1998. Washington DC.

US Congress. House Committee on Resources, Subcommittee on Water and Power Resources. 1998a. Legislative Hearing on H. R.3267—the "Sonny Bono Memorial Salton Sea Reclamation Act." Hearing before the Subcommittee, 105th Congress, first session. Washington DC, 12 March 1998. Congressional Sales Office 169 pp.

US Congress. House Committee on Resources, Subcommittee on Water and Power Resources. 1998b. Oversight Hearing Before the Subcommittee, 105th Congress, first session. Palm Desert CA, 3 October 1998. Congressional Sales Office, Washington DC. 112 pp.

US Congress. House Committee on Rules. 1998c. Providing for the Consideration of H.R. 3267, The Sonny Bono Memorial Salton Sea Reclamation Act. 105th Congress, second session, 14 July 1998. Congressional Sales Office, Washington DC. 10 pp.

US Congress. Senate Committee on Indian Affairs. 1996a. Providing for the Settlement of Issues and Claims Related to the Trust Lands of the Torres-Martínez Desert Cahuilla Indians, and for Other Purposes. Report to accompany S. 1893. 30 pp.

US Congress. Senate Committee on Indian Affairs. 1996b. Torres-Martínez Desert Cahuilla Indians Claims Settlement Act and Additional Lands within the State of Utah for the Goshute Indians. Hearing on July 18, 1996. 55 pp.

US Department of the Interior and The Resources Agency of California. 1969. Salton Sea Project, California: Federal-State Reconnaissance Report. US Dept. Interior and Resources Agency Calif. 160 pp. **M**

US Department of the Interior and The Resources Agency of California. 1974a. Salton Sea Project, California: Federal-State Feasibility Report. US Dept. Interior and Resources Agency Calif. 139 pp. **M**

US Department of the Interior and The Resources Agency of California. 1974b. Salton Sea Project, California. Draft Environmental Impact Statement. US Dept. Interior and Resources Agency Calif. 101 pp. + appendices. **M**

US Federal Water Quality Administration. 1970. Salton Sea, California: Water Quality and Ecological Management Considerations. Fed. Water Qual. Admin., Southwest Region Office, San Francisco CA. 54 pp.

US Fish and Wildlife Service. 1984. Endangered and threatened wildlife and plants: determination of endangered status and critical habitat for the desert pupfish. Federal Register, Rules and Regulations, 51 (61): 10843–10851.

US Fish and Wildlife Service. 1993. Wildlife of Salton Sea National Wildlife Refuge, California. US Fish Wildlife Serv. 15 pp.

US Fish and Wildlife Service. 1997. Salton Sea National Wildlife Refuge California: Watchable Wildlife. US Fish Wildlife Serv. 28 pp. **M**

US Fish and Wildlife Service. 1998. Saving the Salton Sea: A Research Needs Assessment. US Fish Wildlife Serv., Calif. Bur. Reclam., US Geol. Surv. Biol. Resources Div., US Geol. Surv. Water Resources Div. 98–0688-M. 96 pp.

US Fish and Wildlife Service. 1999a. Ecological services list of endangered, threatened, and proposed

species that occur in the study area for the proposed Salton Sea Restoration Project, Imperial, Riverside, San Bernardino, San Diego Counties, California. US Fish Wildlife Serv. 1-6-99-SP-040.

US Fish and Wildlife Service. 1999b. Sonny Bono Salton Sea National Wildlife Refuge Complex. US Fish Wildlife Serv. 20 pp. ⟨pacific.fws.gov/salton/⟩

US Geological Survey. 1966. Hydrology and physiography of the Salton Sea, California. US Geol. Surv. Hydrologic Investigation Atlas HA-222.

US Geological Survey. 1968. The Borrego Mountain Earthquake of April 9, 1968, US Geol. Surv. Prof. Pap. 787. 207 pp.

US Geological Survey. 1982. The Imperial Valley, California, Earthquake of October 15, 1979. US Geol. Surv. Prof. Pap. 1254. 451 pp.

US Geological Survey Biological Resources Division. 1998. Reconnaissance of microbial (bacterial and viral) pathogens in the Salton Sea. Prepared for the Salton Sea Authority. Salton Sea Database Program, U. of Redlands, CA. ⟨www.institute.redlands.edu/Salton/recon/index.aspx⟩ **M**

US Geological Survey National Wildlife Health Center. 2000. A number of reports on several avian diseases available from: ⟨www.nwhc.usgs.gov/⟩ **M**

US Public Health Service. 1996. The New River: Petitioned Public Health Consultation, Imperial Valley, California. Public Health Serv. Agency Toxic Subs. Disease Registry. Div. Health Assess. Consul., Atlanta GA. 48 pp. **M**

US Secretary of the Interior. 1922. Problems of Imperial Valley and Vicinity. Letter from Secretary of the Interior to the 67th Congress. US Gov. Printing Office, Washington DC. 326 pp.

US Water Quality Administration. 1970. Salton Sea, California: water quality and ecological management considerations. Fed. Water Qual. Admin., Pacific Southwest Region. 53 pp.

Usinger, R. L., ed. 1968. Aquatic Insects of California, with Keys to North American Genera and California Species. Univ. Calif. Press, Berkeley CA. 508 pp. **M**

Van Andel, T. H., and G. O. Shor, Jr., eds. 1964. Marine Geology of the Gulf of California: a Symposium. Amer. Assoc. Petrol. Geol., Tulsa OK. 408 pp.

VanCuren, T. 1995. Air pollution in the California desert: a planning perspective. pp. 489–510 in: J. Latting, and P. G. Rowlands, eds. The California Desert: An Introduction to Natural Resources and Man's Impact. June Latting Books, Riverside CA.

Van de Kamp, P. C. 1973. Holocene continental sedimentation in the Salton Basin, California: a reconnaissance. Geol. Soc. Amer. Bull. 84: 827–848. Reprinted in: Imperial Valley Regional Geothermal Exploration. Amer. Assoc. Petrol. Geol. Trip 2. 1973. Annual Meeting Amer. Assoc. Petrol. Geol. 56 pp. **M**

VanDerveer, W. D., and S. P. Canton. 1997. Selenium sediment toxicity thresholds and derivation of water quality criteria for freshwater biota of western streams. Environ. Toxicol. Contam. 16: 1260–1268.

Van Syoc, R. J. 1992. Living and fossil populations of a western Atlantic barnacle, *Balanus subalbidus* Henry, 1974, in the Gulf of California region. San Diego Soc. Natural Hist. Proc. 12: 1–7

Veatch, J. A. 1858. Notes on a visit to the mud volcanoes in the Colorado Desert in the month of July, 1857. Amer. J. Sci. Arts 26: 288–295.

Vedder, J. G., D. Traxler, and P. Fischer. 1993. Imperial Valley Regional Geothermal Exploration. Amer. Assoc. Petrol. Geol. Trip 2. Annual Meeting Amer. Assoc. Petrol. Geol. 56 pp. **M**

Veit, R. R. 1988. Identification of the Salton Sea, California rufous-necked sandpiper. Western Birds, 19: 165–169.

Ver Planck, W. E. 1958. Salt in California. Calif. Div. Mines Bull. 175: 168 pp.

Vincent, K., ed. 1999. Alternative Futures for the Salton Sea. Univ. Calif. Inst. Mexico US, Riverside CA. 23 pp.

Vinson, A. E. 1914. Variations in composition and concentration of water of Salton Sea 1912 and 1913. pp. 47–48 in D. T. MacDougal, ed. The Salton Sea: a Study of the Geography, the Geology, the Floristics, and the Ecology of a Desert Basin. Carnegie Inst. Washington Publ. 193L.

Vitt, L. J., and R. D. Ohmart. 1978. Herpetofauna of the lower Rio Colorado: Davis Dam to the Mexican border. Western Found. Vert. Zool. Proc. 2: 35–72.

Vitton, B. A. 1968. The Effects of Oxygen Tension, Salinity, Temperature and Crowding on the

Distribution, Growth, and Survival of *Balanus amphitrite* Darwin in the Salton Sea, California. MA thesis, San Diego State Univ., San Diego CA. 151 pp.

Vogl, R. J., and L. T. McHargue. 1966. Vegetation of California fan palm oases on the San Andreas Fault. Ecology, 47: 533–540. **M**

Vogl, R, R. N. Henry, and D. S. Lipton. 2000. Characteristics and contaminants of the Salton Sea sediments. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract). **M**

von Brand, T., M. O. Nolan, and E. R. Mann. 1948. Observations on the respiration of *Australorbis glabratus* and some other aquatic snails. Biol. Bull. 95: 199–213. **M**

von Brand, T., H. D. Baerstein, and B. Mehlman. 1950. Studies on the anaerobic metabolism and the aerobic carbohydrate consumption of some freshwater snails. Biol. Bull. 98: 266–278. **M**

Vonck, A. P. M. A., S. E. W. Bonga, and G. Flik. 1998. Sodium and calcium balance in Mozambique tilapia, *Oreochromis mossambicus,* raised at different salinities. Comp. Biochem. Physiol. 119A: 441–449. **M**

von Werlhof, J. 2001. Notes on the Desert Cahuilla and their Yuman neighbors. in L. R. McCrown ed. The Archaeol. Surv. Assoc. of Southern California's The Lake LeConte Survey. San Bernardino County Museum Quarterly 48(3) 21–35. **M**

von Werlhof, J., and K. McNitt. 1980. Archaeological Examinations of the Republic Geothermal Field, East Mesa, Imperial County. Report on file at the Southeast Information Center, Imperial Valley College Museum, El Centro CA.

Wahlin, B. T., J. A. Replogle, and A. J. Clemmens. 1997. Measurement Accuracy for Major Surface-water Flows Entering and Leaving the Imperial Valley. Prepared for Imperial Irrigation Dist. US Dept. Agriculture, Agriculture Research Serv., US Water Conserv. Lab. Rep. #23. Washington DC. 79 pp.

Walker, B. W., ed. 1961. The Ecology of the Salton Sea, California, in Relation to the Sportfishery. Calif. Dept. Fish Game, Fish Bull. 113: 1–204. **M**

Walker, B. W., R. R. Whitney, and G. W. Barlow. 1961a. The fishes of the Salton Sea. Calif. Dept. Fish Game, Fish Bull. 113: 77–91. **M**

Walker, B. W., R. R. Whitney, and L. H. Carpelan. 1961b. General considerations and recommendations [concerning the Salton Sea and its sportfishery]. Calif. Dept. Fish Game, Fish Bull. 113: 185–192. **M**

Walker, K. F. 1981. A synopsis of ecological information on the saline lake rotifer *Brachionus plicatilis* Müller 1786. pp. 159–167 in W. D. Williams, ed. Salt Lakes. V. Junk, Publ. The Hague, Netherlands. **M**

Wallace, R. E., ed. 1990. The San Andreas Fault System, California: an Overview of the History, Geology, Geomorphology, Geophysics, and Seismicity of the Most Well Known Plate-tectonic Boundary in the World. US Geol. Surv. Prof. Pap. 1515. 283 pp.

Wambaugh, J. 1992. Fugitive Nights. W. Morrow Co, New York City, NY. 336 pp. **M**

Wang., L. H., and C. L. Tsai. 2000. Effects of temperature on the deformity and sex differentiation of tilapia, *Oreochromis mossambicus.* J. Exp. Zool. 286: 534–537. **M**

Wang, W. X., J. K. Qiu, and P. Y. Qian. 1999a. Significance of trophic transfer in predicting the high concentration of zinc in barnacles. Environ. Sci. Technol. 33: 2905–2909. **M**

Wang, W. X., J. K. Qiu, and P. Y. Qian. 1999b. The trophic transfer of Cd, Cr, and Se in the barnacle *Balanus amphitrite.* Mar. Ecol. Prog. Ser. 187: 191–102. **M**

Wang, W. X., I. Stupakoff, and N. S. Fisher. 1999c. Bioavailability of dissolved and sediment-bound metals to a marine deposit-feeding polychaete. Mar. Ecol. Prog. Ser. 178: 281–293. **M**

Ward, G. 1970. Sargo fish is 'limitless.' Outdoor Calif. 31(4): 13.

Ward, J. W. S. 1967. The Cahuilla: a Historical-anthropological Study of a Southern California People. MA thesis. Univ. Southern Calif. 296 pp.

Warnock, N. 1999. Salton Sea studies. Assessing the birds of an inland sea. Point Reyes Bird Observatory Observer 115: 6. **M**

Warnock, N., A. Black, G. Geupel, N. Nur, and W. D. Shuford. 1998. Avifauna of the Salton Sea: annual phenology, numbers, and distribution. Prepared for Salton Sea Authority by Point Reyes Bird Observatory, Palomarin CA. Salton Sea Database Program, U. of Redlands, CA.

Warnock, N., W. D. Shuford, and K. Molina. 2000. The importance of the Salton Sea to Pacific Flyway waterbirds. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract)

Warren, E. von T. 1981. History. pp. 83–105 in E. von T. Warren, R. H. Crabtree, C. N. Warren, M. Knack, and R. McCarty, eds. A Cultural Resources Overview of the Colorado Desert Planning Units. Cult. Resources Publ. US Bureau Land Manag., Calif. Desert Dist. Riverside CA.

Warrick, J. 2000. California's much-maligned Salton Sea is a desert oasis for wildlife. National Wildlife, 38 (5): 12, 14.

Wasklewicz, T. A. and N. Meek. 1995. Provenance of aeolian sediment: the upper Coachella Valley, California. Physical Geograph. 16: 539–556.

Water Education Foundation. 1994. The Salton Sea. Western Water March/April 1994. 11 pp.

Waters, M. R. 1983. Late Quaternary lacustrine chronology and archaeology of ancient Lake Cahuilla, California. Quat. Res. 19: 373–387.

Watkins, R. 1990a. Pliocene channel deposits of oyster shells in the Salton Trough region, California. Palaeogeograph. Palaeoclimatol. Palaeoecol. 79: 249–262. **M**

Watkins, R. 1990b. Paleoecology of a Pliocene rocky shoreline, Salton Trough region, California. Palaios 5: 167–175.

Watkins, R. 1992. Sedimentology and paleoecology of Pliocene shallow marine conglomerates, Salton Trough region, California. Palaeogeograph. Palaeoclimatol. Palaeoecol. 95: 319–333.

Watkins, T. H. 1969. The Grand Canyon: the Story of a River and its Canyons. Amer. West. Publ. Co., Palo Alto CA. 310 pp.

Weatherford, G. D., and F. L. Brown, eds. 1986a. New Courses for the Colorado River: Major Issues for the Next Century. Univ. New Mexico Press, Albuquerque NM. 253 pp. **M**

Weatherford, G. D., and F. L. Brown. 1986b. Epilog: high water, carbon dioxide, and pig feathers. pp. 225–231 in G. D. Weatherford, and F. L. Brown, eds. New Courses for the Colorado River: Major Issues for the Next Century. Univ. New Mexico Press, Albuquerque NM. **M**

Weeks, L. L. 1966. Salton Sea, Depository of Agricultural Wastes. Coachella Valley Water District, Coachella CA. 15 pp. **M**

Weide, M. L. 1976a. Regional environmental history of the Yuha Desert. pp. 9–20 in P. J. Wilke, ed. Background to the Prehistory of the Yuha Desert Region. Ballena Press Anthropol. Papers #5. Ramona CA.

Weide, M. L. 1976b. A cultural sequence for the Yuha Desert. pp. 81–94 in P. J. Wilke, ed. Background to the Prehistory of the Yuha Desert Region. Ballena Press Anthropol. Papers #5. Ramona CA.

Weight, H. L. 1948. Nature's freaks on Salton shore. Desert Mag. 11 (June): 5–8.

Weight, H. L. 1949. Fossil shells from a vanished sea. Desert Mag. 12 (October): 21–26.

Weight, H. L. 1959. Lost Ships of the Desert: a Legend of the Southwest. Calico Press, Twentynine Palms CA.

Wells, A. J. 1907. Capturing the Colorado: how the biggest engineering battle of modern times has been fought in the great southwest to save the Imperial empire. Sunset Mag. 18(5): 391–404.

Wells, H., and P. Martz. 1976. Cultural Resource Inventory for the Cabazon Indian Reservation. Prepared by the Archaeol. Research Unit, Univ. California, Riverside, for the US National Park Service, Western Archaeol. Center, Tucson AZ.

WESTEC Services, Inc. 1981. Solar Pond Project, Salton Sea, California. Final Report Prepared for Jet Propulsion Laboratory, Calif. Inst. Tech. Variously paginated. **M**

Whistler, D. P., E. B. Lander, and M. A. Roeder. 1995. A diverse record of microfossils and fossil plants, invertebrates, and small vertebrates from the late Holocene Lake Cahuilla Series, Riverside County, California. pp. 109–118 in P. Remeika and A. Sturz, eds. Paleontology and Geology of the Western Salton Trough Detachment, Anza-Borrego Desert State Park, California. Field Trip Guidebook and Volume for the 1995 San Diego Assoc. Geol. Field Trip to Anza-Borrego Desert State Park. San Diego Assoc. Geol., San Diego CA. **M**

White, D. E. 1957a. Thermal waters of volcanic origin. Geol. Soc. Amer. Bull. 68: 1637–1658.

White, D. E. 1957b. Magmatic, connate, and metamorphic waters. Geol. Soc. Amer. Bull. 68: 1659–1682.

White, D. E., E. T. Anderson, and D. K. Grubbs. 1963. Geothermal brine well: mile-deep drill hole may tap ore-bearing magmatic water and rocks undergoing metamorphism. Science 139: 919–922. **M**

White, M. D., and C. M. Hart. 1996 Salton Sea Management Project: evaluation of salinity and elevation management alternatives. Ogden Environmental and Energy Services, Inc. Prepared for Salton Sea Authority. 7 pp. **M**

White, P. M., and S. D. Fitt. eds. 1998. Bibliography of the Indians of San Diego County: the Ku-

meyaay, Diegeño, Luiseño, and Cupeño. Native Amer. Bibliog. Ser. #21. Scarecrow Press, Lanham MD.

Whitney, R. R. 1961a. The bairdiella, *Bairdiella icistius* (Jordan and Gilbert) [in the Salton Sea]. Calif. Dept. Fish Game, Fish Bull. 113: 105–151. **M**

Whitney, R. R. 1961b. The orangemouth corvina, *Cynoscion xanthulus* Jordan and Gilbert [in the Salton Sea]. Calif. Dept. Fish Game, Fish Bull. 113: 165–183. **M**

Whitney, R. R. 1967. Introduction of commercially important species into inland mineral waters: a review. Texas Univ. Contrib. Mar. Sci. 12: 262–280.

Wilber, S. R. 1974. The Literature of the California Black Rail. US Fish Wildlife Serv., Washington DC, Sp. Sci. Rep. #179. 17 p.

Wilber, S. R. 1987. Birds of Baja California. Univ. Calif. Press, Berkeley CA. 253 pp.

Wiley, W. D. 1950. The salt in Salton Sea. Desert Mag. 15 (10): 26–28,

Wilke, P. J. 1975a. The Cahuilla Indians of the Colorado Desert: Ethnohistory and Prehistory. Ballena Press, Ramona CA.

Wilke, P. J., ed. 1975b. Background to the Prehistory of the Yuha Desert Region. Ballena Press Anthropol. Papers #5. Ballena Press, Ramona CA.

Wilke, P. J. 1976a. Late Prehistoric Human Ecology at Lake Cahuilla, Coachella Valley, California. Contrib. Univ. Calif. Archaeol. Res. Facility #38. 168 pp. **M**

Wilke, P. J. 1976b. Late Prehistoric Human Ecology at Lake Cahuilla, Coachella Valley, California. PhD thesis, Univ. Calif., Riverside CA. (in Anthropology). 243 pp.

Wilke, P. J. 1978. Late prehistoric human ecology at Lake Cahuilla, Coachella Valley, California. Univ. Calif. Archaeol. Research Facility Contrib. #18.

Wilke, P. J. 1980. Prehistoric weir fishing on recessional shorelines of Lake Cahuilla, Salton Basin, southeastern California. Desert Fishes Council Proc. Ann. Symp. 11: 101–102. **M**

Wilke, P. J., and H. W. Lawton. 1975. Early observations on the cultural geography of the Coachella Valley. pp. 9–43 in P. J. Wilke et al., ed. The Cahuilla Indians of the Colorado Desert: Ethnohistory and Prehistory. Ballena Press, Ramona CA. **M**

Wilke, P. J., and A. M. McDonald. 1989. Prehistoric use of rock-lined cache pits: California deserts and southwest. J. Calif. Great Basin Anthropol. 11: 50–73.

Wilke, P. J., H. W. Lawton, T. F. King, and S. Hammond. 1975. The Cahuilla Indians of the Colorado Desert: Ethnohistory and Prehistory. Ballena Press, Ramona CA. 73 pp. **M**

Willett, G. 1945. The *Acteocina* of Salton Sea, Colorado Desert, California. South. Calif. Acad. Sci. Bull. 44: 28–29. **M**

Williams, J. E., D. B. Bowman, J. E. Brooks, A. A. Echelle, R. J. Edwards, D. A. Hendrickson, and J. J. Landye. 1985. Endangered aquatic ecosystems in North American deserts with a list of vanishing fishes of the region. J. Arizona-Nevada Acad. Sci. 20: 1–61. **M**

Williams, W. D., ed. 1981. Salt Lakes: Proceedings of International Symposium on Athalassic (Inland) Salt Lakes. W. Junk, The Hague, Netherlands. 444 pp. Reprinted from Hydrobiologia 81/82.

Williams, W. D., ed. 1991. Salt Lakes and Salinity. Kluwer Acad. Publ. Boston. 160 pp. Reprinted from Hydrobiologia 210.

Wilson, M. E. and S. H. Wood. 1980. Tectonic tilt rates derived from lake-level measurements, Salton Sea, California. Science 207: 183–185.

Winkler, D. W., ed. 1977. An Ecological Study of Mono Lake, California. Univ. Calif. Davis, Inst. Ecol. Publ. 12. 184 pp. **M**

Winspear, N. R., and K. Pye. 1995. Sand supply to the Algodones dunefield, south-eastern California, USA. Sedimentology 42: 875–891. **M**

Wolcott, M. J., and B. M. Berlowski. 2000. A bacterial pathogen reconnaissance of the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract). **M**

Wood, A. M., S. Miller, and R. Castenholz. 2000. Cyanobacteria of the Salton Sea. Salton Sea Symposium III. Salton Sea Authority and US Bur. Reclam. Desert Hot Springs CA, 13–14 January 2000. (abstract) **M**

Woodbury, D. O. 1941. The Colorado Conquest. Dodd, Mead and Co., New York City NY. 367 pp. **M**

Wright, H. B. 1911. The Winning of Barbara Worth. A. L. Burt Co., Chicago IL. 510 pp. **M**

Wright, W. 1980. Water in a desert valley. Western Tanager (Los Angeles Audubon Society) 6(9): 1–5.

Wu, L., G. Banuelos, and X. Guo. 2000. Changes of soil and plant tissue selenium status in an upland

grassland contaminated by selenium-rich agricultural drainage sediment after ten years transformed from a wetland habitat. Ecotoxicol. Environ. Safety 47: 201–209.

Wurtsbaugh, E. A. 1992. Food-web modification by an invertebrate predator in the Great Salt Lake (USA). Oecologia 89: 168–175.

Wynn, M. R. 1975. Next door to Hell's kitchen. Westways (South. Calif. Auto Club) February 1975: 27–31, 88. **M**

Yaseen, A. E. 1996. The chromosomes of the Egyptian freshwater snail *Melanoides tuberculata* (Gastropoda: Prosobranchia. J. Molluscan Stud. 62: 499–500.

Yohe, R. M., II. 1998. Notes on the late prehistoric extension of the range for the muskrat (*Ondatra zibethicus*) along the ancient shoreline of Lake Cahuilla, Coachella Valley, Riverside County, California. South. Calif. Acad. Sci. Bull. 97: 86–88. **M**

Young, D. R. 1970. The Distribution of Cesium, Rubidium, and Potassium in the Quasi-Marine Ecosystem of the Salton Sea. PhD thesis, University of California, San Diego. 213 pp. **M**

Yufera, M., G. Parra, and E. Pascual. 1997. Energy content of rotifers (*Brachionus plicatilis* and *Brachionus rotundiformis*) in relation to temperature. Hydrobiologia 258: 83–87. **M**

Zajac, R. N. 1991. Population ecology of *Polydora ligni* (Polychaeta, Spionidae). 1. Seasonal variation in population characteristics and reproductive activity. Mar. Ecol. Prog. Ser. 77: 197–206.

Zengel, S. A., and E. P. Glenn. 1996. Presence of the endangered desert pupfish (*Cyprinodon macularius,* Cyprinodontidae) in Ciénega de Santa Clara, Mexico, following an extensive marsh drydown. Southwestern Naturalist, 41: 73–78. **M**

Zengel, S. A., V. J. Meretsky, E. P. Glenn, R. S. Felger, and D. Ortiz. 1995. Cienega de Santa Clara, a remnant wetland in the Rio Colorado delta (Mexico): vegetation distribution and the effects of water flow reduction. Ecol. Engineer 4: 19–36.

Table I. Concentrations of major ions in the ocean and in the Salton Sea.*

	1964 Open Ocean Water mM	1907 Salton Sea mM	1948 Salton Sea mM	1962–1964 Salton Sea mM	1986 Salton Sea mM	1999 Salton Sea mM
Ca^{2+}	10.23	2.47	20.05	19.65	15.00	25.15
Mg^{2+}	53.57	2.63	40.82	40.00	49.37	57.05
Na^{1+}	470.20	48.26	514.09	423.61	408.87	537.22
K^{1+}	9.96	0.59	4.91		4.86	
Co_3^{2-}		1.10	0.35			
HCO_3^{1-}	2.34		2.80	2.89		4.03
SO_4^{2-}	28.25	4.96	78.56	74.27	87.50	117.04
Cl^{1-}	548.30	47.80	478.60	390.00	394.89	460.71
Salinity g l^{-1}	34.33	3.55	38.55	32.52	34.00	42.50
Reference	Potts and Perry 1964	Ross 1914	Carpelan 1961b	Hely et al. 1966	Oglesby pers. obs.	SSA[1] and USBR[2] 2000a

* Units were converted from mg/l, parts per thousand, or parts per million.
[1] SSA: Salton Sea Authority.
[2] USBR: US Bureau of Reclamation.

Table II. Nutrient concentrations in rivers and agricultural waters.*

	Drains Other Than Rivers 1968–1969 Average µM	Whitewater River 1980–1993 Average µM	Alamo River 1980–1993 Average µM	New River 1980–1993 Average µM
Ammonia	10.7	13.5	61.2	88.2
Nitrite	2.9			
Nitrate	712.9	8.1	129.8	80.0
Phosphate	1.3	2.5	7.2	9.4
Reference	USDI[1] and RAC[2] 1969	SSA[3] and USBR[4] 2000a	SSA[3] and USBR[4] 2000a	SSA[3] and USBR[4] 2000a

* Units were converted from mg/l.
[1] USDI: US Department of Interior.
[2] RAC: Resources Agency of California.
[3] SSA: Salton Sea Authority.
[4] USBR: US Bureau of Reclamation.

Table III. Nutrient concentrations in the Salton Sea.*

	1954–1956 Average μM	1954–1956 Highest μM	1968–1969 Average μM	1980–1993 Average μM	1999 Average μM
Ammonia	4.8–12.3	40.0	21.4	48.8	76.6
Nitrite			1.9		
Nitrate	0.78–7.63	30.0	10.0	3.1	
Phosphate	0.45–1.10	4.2	1.2	3.6	2.3
Reference	Carpelan 1961b	Carpelan 1961b	USDI[1] and RAC[2] 1969	SSA[3] and USBR[4] 2000a	SSA[3] and USBR[4] 2000a

* Units were converted from mg/l.
[1] USDI: US Department of Interior.
[2] RAC: Resources Agency of California.
[3] SSA: Salton Sea Authority.
[4] USBR: US Bureau of Reclamation.

Table IV. Prokaryotes, unicellular algae, and protozoa of the Salton Sea.

Scientific name	B, Pl, or Pa*	Notes	Reference
Prokaryota			
Archaea		No Archaea have been reported from the Salton Sea.	
Eubacteria			
Cyanophyta			
Calothrix sp.	B	Mat forming. Serves as substrate for filamentous benthic diatom growth. Probably the major agent for tufa deposition.	Carpelan 1961c
Gomphosphaeria lacustris	Pl	Present in 1950s.	Carpelan 1961c
Hydrocoleum sp.	B	Mat forming.	Carpelan 1961c
Lyngbya sp.	Pl	Present in 1950s.	Carpelan 1961c
Microcystis sp.	Pl	Secretes a toxin called microcystin, believed by some to be the cause of a major die-off of wintering eared grebes (*Podiceps nigricollis*) in 1991–1992, but no scientific evidence exists.	*Los Angeles Times* 25 April 1995
Oscillatoria sp. nr. *O. laetevirens*	B	Mat forming.	Carpelan 1961c
Phormidium tenui	B	Mat forming.	Carpelan 1961c
Plectonema calotrichoides	B	Mat forming.	Carpelan 1961c
Pleurocapsis crepidinum	B	Mat forming.	Carpelan 1961c
Pleurococcus turgidus	B	Mat forming.	Carpelan 1961c
Spirulina major	B	Mat forming.	Carpelan 1961c
Other eubacteria			
Beggiatoa sp.	B	Sulfur-oxidizing bacterium in bottom sediments.	Carpelan 1958
Clostridium botulinum Type C	Pa	Causes avian botulism, the toxin botulinum actually produced by bacteriophages. At the Salton Sea, this anaerobe afflicts coots and puddle ducks in summers. They eat rotting and anaerobic vegetation. Known to cause major bird kills for a number of decades. See text.	US Geological Survey National Wildlife Health Center. 2000. See text.

Table IV. Continued.

Scientific name	B, Pl, or Pa*	Notes	Reference
Pasturella multocida Type 1	Pa	Causes avian cholera. Very contagious from bird to bird as well as by contaminated soil, food, and water. Chiefly afflicts wintering ducks and geese. Known to cause major bird kills for a number of decades. See text.	Franson et al. 2000; US Geological Survey National Wildlife Health Center 2000. See text.
Salmonella sp.	Pa	Usually overlooked, but causes a few bird deaths every year, and a major kill of cattle egrets in 1998. See text.	Salton Sea Authority and US Bureau of Reclamation 2000a
Streptococcus sp.	Pa	Found on Salton Sea *Oreochromis.*	Costa-Pierce 1998
Vibrio alginolyticus	B, Pa	Involved with *Clostridium botulinum* in kills of piscivorous birds. See text.	Kuperman and Matey 2000. See text.
Vibrio damsela	B, Pa	Involved with *Clostridium botulinum* in kills of piscivorous birds. See text.	Kuperman and Matey 2000. See text.
Vibrio vulnificus	B, Pa	Involved with *Clostridium botulinum* in kills of piscivorous birds. See text.	Kuperman and Matey 2000. See text.
Eukaryota			
Algae			
Bacillariophyta (diatoms)			
Cyclotella caspia	Pl	Common planktonic diatom in 1950s.	Carpelan 1961c; Oglesby pers. obs.
Cyclotella sp. nr. *C. caspia*	Pl	Common planktonic diatom in 1950s.	Carpelan 1961c; Oglesby pers. obs.
Cyclotella sp.	Pl	Common in 1990s. This species is very small.	Hurlbert cited by Salton Sea Authority and US Bureau of Reclamation 2000a; Tiffany et al. 2000b
Cylindrotheca sp.	Pl	Present in 1950s.	Carpelan 1961c
Gyrosigma balticum	Pl	Unusual in being so far inland.	Sterrenburg et al. 2000
Gyrosigma wormlei	Pl	Common in 1990s. Formerly thought to be only a freshwater species.	Sterrenburg et al. 2000
Gyrosigma sp.	Pl	Present in 1950s.	Carpelan 1961c; Oglesby pers. obs.
Navicula sp.	Pl	Present in 1950s.	Carpelan 1961c; Oglesby pers. obs.
Nitzschia longissima	Pl	Common planktonic diatom in the 1950s. Could be *Nitzschia* sp. nr. *N. closterium.*	Carpelan 1961c; Oglesby pers. obs.
Nitzschia sigmoides	B, Pl	Benthic: the major species of "filamentous" diatom growing on shallow hard substrates. Colonies are non-integrated, brown. See text.	Oglesby pers. obs. See text.

Table IV. Continued.

Scientific name	B, Pl, or Pa*	Notes	Reference
Pleurosigma ambrosianum	Pl	Common in 1990s; dominant species in winter.	Sterrenburg et al. 2000
Pleurosigma sp.	Pl	Present in 1950s, as part of the filamentous diatom complex.	Carpelan 1961c; Oglesby pers. obs.
Synedra sp.	Pl	Present in 1950s.	Carpelan 1961c
Thalassionema nitzchioides	Pl	Present in 1950s, common in 1990s.	Carpelan 1961c; Hurlbert cited by Salton Sea Authority and US Bureau of Reclamation 2000a; Tiffany et al. 2000b; Oglesby pers. obs.
Chlorophyta			
Chlorophyceae			
Crucigenia rectangularis	Pl	Present in 1950s.	Carpelan 1961c
Oöcystis sp.	Pl	Present in the 1950s.	Carpelan 1961c
Westella botryoides	Pl	Present in the 1950s.	Carpelan 1961c
Chrysophyta			
Chrysophyceae			
Dictyocha sp.	Pl	Silicoflagellate. Present in 1950s.	Carpelan 1961c; Oglesby pers. obs.
Hermesium adriaticum	B	Silicoflagellate. Present in 1950s, 1990s.	Tiffany 2000
Haptophyceae			
Pleurochrysis pseudoroscoffensis	Pl	Coccolithophore. Rare before 1999, dense in surface film in February through June 1999. Potentially toxic.	Coe et al. 2000; Reifel et al. 2000b
Prymnesium sp.	Pl	Coccolithophore. Present in 1990s. Potentially toxic.	Reifel et al. 2000a
	Pl	Coccolithophores, unidentified. Present in 1950s.	Carpelan 1961c
Raphidiophyceae			
(= Chloromonadaphyceae)			
Chattonella marina	Pl	=*C. subsolis*. Potentially toxic. See text.	Horvitz 2000; Tiffany et al. 2000. See text.
Crytophyta			
Crytophyceae			
Crytomonas sp.	Pl	Present in 1950s.	Carpelan 1961c

Table IV. Continued.

Scientific name	B, Pl, or Pa*	Notes	Reference
Euglenophyta			
Euglenophyceae			
Eutreptia lanowii	Pl	Present in 1950s.	Carpelan 1961c
Pyrrophyta			
Dinophyceae			
Amphidinium kofoidii	Pl	Present in 1950s.	Carpelan 1961c
Amyloödinium ocellatum	Pa	Major gill and skin parasite, particularly afflicting tilapia at the Salton Sea. See text.	Kuperman and Matey 2000. See text.
Exuviella marina	Pl	Common in 1950s and 1990s.	Carpelan 1961c; Tiffany et al. 2000
Exuviella trochoideum	Pl	In 1950s one of two commonest dinoflagellates; common in 1990s.	Carpelan 1961c; Tiffany et al. 2000; Oglesby pers. obs.
Glenodinium sp.	Pl	In 1950s one of two commonest dinoflagellates; common in 1990s.	Carpelan 1961c; Tiffany et al. 2000; Oglesby pers. obs.
Gonyaulax sp.	Pl	Present in 1950s.	Carpelan 1961c
Gymnodinium sp.	Pl	Present in 1990s. Potentially toxic.	Reifel et al. 2000a; Tiffany et al. 2000b
Gyrodinium splendens	Pl	Present in 1950s.	Carpelan 1961c
Gyrodinium uncatenum	Pl	Present in 1990s. Potentially toxic.	Reifel et al. 2000a; Tiffany et al. 2000b
Heterocapsea niei	Pl	= *Cachonina niei.* Common in 1990s. Potentially toxic.	Reifel et al. 2000a; Tiffany et al. 2000b
Peridinium trochoideum	Pl	Present in 1950s.	Carpelan 1961c
Porocentrum sp.	Pl	Common in 1950s	Carpelan 1961c; Tiffany et al. 2000b
Scrippsiella sp.	Pl	Present in 1990s.	Tiffany et al. 2000b
Rhodophyta			
Asterocystis ornata	B	Red alga, present in 1950s. Grows epiphytically on filamentous algae near drains	Carpelan 1961c
Eukaryota "protozoans"			
Ciliata			
Cyrtophorida			
Dystera sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Kuperman and Matey 2000

Table IV. Continued.

Scientific name	B, Pl, or Pa*	Notes	Reference
Heterotrichida			
Fabrea salina	B, Pl	Large benthic ciliate. Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	B. W. Walker 1961; Hurlbert et al. 2000; Small and Gebler 2000
Peristromus sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Hymenostomida			
Frontonia sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Hypotrichida			
Blepharisma sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Euplotes sp.	B, Pl	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	B. W. Walker 1961; Small and Gebler 2000; Hurlbert et al. 2000
Holosticha sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Stylonychia sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Uroleptus sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Uronychia sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Urostrongylus sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000

Table IV. Continued.

Scientific name	B, Pl, or Pa*	Notes	Reference
Karyorelictida			
Trachelocerca sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Oligotrichida			
Halta sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	B. W. Walker 1961; Hurlbert et al. 2000; Small and Gebler 2000
Peritrichida			
Ambiphyra ameiuri	Pa	Skin and gill parasite on tilapia and bairdiella, often very abundant.	Kuperman and Matey 2000
Epistylus sp.	Pa	Parasite on skin and parapodia of pileworm *Nereis succinea.*	Kuperman and Matey 2000
Rhabdostyla vernalis	Pa	Parasitizes exoskeleton of copepod *Apocyclops dengizicus.*	Kuperman and Matey 2000
Protostomida			
Coleps hirtus	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Sessilida			
Carchesmium sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Epistylis sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et ai. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Vorticella sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Suctorida			
Acineta sp.	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000

Table IV. Continued.

Scientific name	B, Pl, or Pa*	Notes	Reference
Synmeniida			
Eucamptocerca longa	B	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Linsley and Carpelan 1961; Simpson et al. 1998; Hurlbert et al. 2000; Small and Gebler 2000
Tintinnida			
Strombidium (3 spp.)	B, Pl	Most benthic ciliates feed on diatoms or bacteria, but not apparently on dinoflagellates.	Hurlbert et al. 2000; Small and Gebler 2000; Oglesby pers. obs.
Sarcomastigophora			
Mastigophora			
Zoomastigophorea			
Cryptobia branchialis		Gill parasite on tilapia. Associated with autumn 1997 outbreak at Bombay Beach.	Kuperman and Matey 2000
Sarcodina			
Rhizopoda (foraminiferans)			
Foraminifera			
Ammobaculites salsus	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1958, 1961
Bolivina striatula	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1958, 1961
Buliminella elegantissima	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1958, 1961
Calcituba simplex	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1958, 1961
Elphidium tumidum	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	F. L. Rogers 1949; Arnal 1958, 1961
Quinqueloculina bellatula	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1958, 1961
Quinqueloculina rhodiensis	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1958, 1961
Quinqueloculina subdecorata	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1958, 1961

Table IV. Continued.

Scientific name	B, Pl, or Pa*	Notes	Reference
Quinqueloculina sp.	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	F. L. Rogers 1949
Rheophax nana	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1961
Rotalia sp.	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	F. L. Rogers 1949
Saccammino sphaericea	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1961
Streblus tepidus	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1961
Textularia earlandii	B	Most benthic foraminifera feed on diatoms or bacteria, but not apparently on dinoflagellates.	Arnal 1958, 1961
Lobosa			
spp.	B	Testate amoeba. Feeds on organic detritus and bacteria tightly bound to sediment particles.	Arnal 1958
spp.	B	Naked or lobose amoeba. Feeds on organic detritus and bacteria tightly bound to sediment particles.	Linsley and Carpelan 1961; Hurlbert et al. 2000
spp.	Pl	Radiolarians.	Linsley and Carpelan 1961
Gromia sp.	B	Filosan. Feeds on organic detritus and bacteria tightly bound to sediment particles.	Hurlbert et al. 2000

Table incomplete.
* B, Pl, or Pa: Benthic, Planktonic, or Pathogenic.

Table V. Aquatic, semi-aquatic, and riparian plants of the Salton Trough.*

Scientific name	Common name	I**	Notes	Reference
Charophyta				
Chara sp.	Stonewort		Sometimes common in drains, slow moving streams. Cleveland Street Spillway.	Oglesby pers. obs.
Chlorophyta				
Cladophora spp.	Filamentous pond scum		Common, widespread in drains, streams, springs. Cleveland Street Spillway, Whitefield Creek. See text.	Carpelan 1961c; Oglesby pers. obs. See text.
Enteromorpha sp.	Tubular alga	I	Common tubular alga on tideless intertidal rocks along shoreline and at mouths of drains and rivers. Salton Sea State Recreation Area, Red Hill Marina, mouth of Alamo River. Euryhaline, often found in low salinity waters. Native to marine and estuarine habitats along Pacific Coast. See text.	Carpelan 1961c; Oglesby pers. obs. See text.
Pteridophyta				
Salviniaceae				
Salvinia molesta	Floating fern	I	Noxious invasive floating weed, recognized in Imperial Valley in 1999. Clogs and deoxygenates lakes, reservoirs, and irrigation canals. Native to South America. See text.	*Los Angeles Times* 23 September 1999. See text.
Angiospermae				
Dicotyledones				
Aizoaceae				
Sesuvium verrucosum	Western sea-purslane		Alkali marsh, saline wetlands, dikes. Perennial, low growing, many stems, red-purple flowers.	SSA USBR[2] 2000a; Oglesby pers. obs.
Trianthema portulacastrum	Horse-purslane		Irrigation ditches, seasonally dry wetlands.	Mason 1957
Asteraceae				
Baccharis salicifolia	Seep willow, mule fat, water-wally		= *B. viminea, B. glutinosa.* Often dense thickets at springs and seeps desert washes.	Mason 1957; Lindsay 2001
Bebbia juncea aspera	Sweetbush		Small, often leafless, shrub. Washes, rocky slopes, plains. Seeds must be scarified by flood waters before they will germinate.	Hayden and Rinnyo 1963

Table V. Continued.

Scientific name	Common name	I**	Notes	Reference
Chloracantha spinosa	Mexican devilweed		= *Aster spinosa.* Seeps, irrigation ditches, saline flats.	Mason 1957
Machaeranthera canescens	Hoary aster		= *Aster canescens, A. tephrodes,* perhaps = *A. asteroides.* Bottom lands.	Mason 1957
Pluchea sericea	Arrowweed, cachanilla		Common riparian shrub; washes, springs, oases, palm oases, saline flats.	Oglesby pers. obs.
Bignoniaceae				
Chilopsis linearis arcuata	Desert willow		Small tree with large, fragrant, pink flowers in summer; winter deciduous. Common in sandy washes.	Oglesby pers. obs.
Boraginaceae				
Heliotropium curassavicum	Seaside heliotrope		Alkali marsh, saline soils, disturbed areas such as dikes. Rhizomatous.	SSA USBR[2] 2000a; Oglesby pers. obs.
Caryophyllaceae				
Spergularia marina	Saltmarsh sand spurry		Alkali and salt marshes; disturbed areas such as dikes and dredge spoil.	SSA USBR[2] 2000a
Chenopodiaceae				
Allenrolfea occidentalis	Iodinebush, shrubby pickleweed		Small woody shrub; leafless with green, jointed stems. Alkali flats and edges of alkali and saline waters.	Oglesby pers. obs.
Atriplex spp.	Saltbush		Many species in washes, riparian woodlands, alkali and saline flats.	Oglesby pers. obs.
Suaeda moquinii	Bush seep-weed		= *S. torreyana,* = *S. fruticosa.* Small shrub. Washes, alkali and saline flats.	Mason 1957; Oglesby pers. obs.
Convolvulaceae				
Cressa truxillensis	Alkali weed		Alkali marsh.	SSA USBR[2] 2000a
Fabaceae				
Acacia greggii	Catclaw acacia		Shrub. Washes.	Oglesby pers. obs.
Cercidium floridum floridum	Palo verde		Usually leafless small tree. Washes. Widely planted.	Oglesby pers. obs.
Olneya tesota	Ironwood		Large shrub or small tree in washes and bottom lands.	Oglesby pers. obs.

Table V. Continued.

Scientific name	Common name	I**	Notes	Reference
Prosopis glandulosa torreyana	Honey mesquite		Riparian, washes, bottom lands, seeps along fault traces.	Oglesby pers. obs.
Prosopis pubescens	Screw-bean mesquite		Riparian, washes, bottom lands, seeps along fault traces.	Oglesby pers. obs.
Psorothamnus emoryi	Smoketree		= *Dalea.* Usually leafless shrub. Washes. Seeds must be scarified by flood waters before they will germinate.	Oglesby pers. obs.
Psorothamnus schottii	Inkweed		= *Dalea.* Shrub. Washes. Seeds must be scarified by flood waters before they will germinate.	Oglesby pers. obs.
Sesbania exaltata	Colorado River hemp, coffee weed		= *S. macrocarpa.* Streams, overflow lands, old cultivated fields.	Mason 1957
Gentianaceae				
Eustoma exaltatum	Catchfly gentian		Large blue, violet, or white flowers. Seasonally dry water courses, alkaline marshes	Mason 1957; Oglesby pers. obs.
Polygonaceae				
Polygonum argyrocoleon	Persian wireweed	I	Marshy ground.	Mason 1957
Rumex maritimus	Golden dock	I	Present in shallow drains and freshwater marshes. Cleveland Street Spillway.	SSA USBR[2] 2000a; Oglesby pers. obs.
Rumex violescens	Dock		Irrigation ditch banks, saline flats.	Mason 1957
Salicaceae				
Populus balsamoides trichocarpa	Black cottonwood, black poplar		Riparian tree; in Salton Trough, along river banks and alluvial bottom lands; widely planted in farmlands.	SSA USBR[2] 2000a; Oglesby pers. obs.
Populus fremontii fremontii	Fremont cottonwood, Fremont poplar, alamo		Riparian tree; in Salton Trough, along river banks and alluvial bottom lands; widely planted in farmlands. The commoner species in the Salton Trough.	SSA USBR[2] 2000a; Oglesby pers. obs.
Salix exigua	Narrow-leaved willow, coyote willow		Common small tree in riparian woodlands, especially along rivers, larger washes, wildlife management areas, springs, seeps, oases.	Oglesby pers. obs.

Table V. Continued.

Scientific name	Common name	I**	Notes	Reference
Salix gooddingii	Willow		Common small tree in riparian woodlands, especially along rivers, larger washes, wildlife management areas, springs, seeps, oases.	Rowlands 1995b
Salix spp.	Willows		Common small tree in riparian woodlands, especially along rivers, larger washes, wildlife management areas, springs, seeps, oases.	Oglesby pers. obs.
Saueraceae				
Anemopsis californica	Lizard tail		Edges of saline waters.	Oglesby pers. obs.
Tamaricaceae				
Tamarix ramosissima	Salt cedar, tamarisk	I	= *T. pentandra,* = *T. chinensis.* Noxious invasive weedy shrub to 8 m tall, forming dense, impenetrable thickets and outcompeting other plants everywhere. Poor wildlife habitat. Causes major environmental changes, soil salinization, and lowers water table. Common in rivers, drains, shoreline pools, marshes, and waterfowl management ponds. Spreads by wind-blown tiny seeds and vegetatively. Very difficult to eradicate. Native to central and east Asia. See text.	Lebo et al. 1982; England and Laudenslayer 1995; Broussard et al. 2000; Oglesby pers. obs. See text.
Angiospermae				
Monocotyledones				
Arecaceae				
Washingtonia filifera	California fan palm		CA's only native palm. Native to springs along San Andreas Fault on east side of Coachella Valley and low mountain stream bottoms on west side of Coachella Valley. Widely planted.	Vogl and McHargue 1966; Cornett 1989; Oglesby pers. obs.
Cyperaceae				
Carex spp.	Sedge		Present in some drains. Whitefield Creek.	Oglesby pers. obs.
Cyperus erythrorhizos	Sedge		= *Carex erythrorhizos.* Irrigation ditches, river banks.	Mason 1957
Eleocharis geniculata			Marshes, stream banks.	Mason 1957

Table V. Continued.

Scientific name	Common name	I**	Notes	Reference
Eleocharis parvula	Small spikerush		= *E. coloradoensis.* Alkali mudflats, irrigation ditches, marshes.	Mason 1957
Eleocharis spp.	Spike rush		Sometimes abundant in springs and slow streams. Whitefield Creek, 1000 Palms Oasis.	Oglesby pers. obs.
Scirpus acutus occidentalis	Spike rush		In larger, less saline, shoreline pools and freshwater marshes.	Hayden and Rinnyo 1963
Scirpus americanus	Bulrush, three-square		= *S. olneyi.* In larger, less saline, shoreline pools and freshwater marshes.	Mason 1957; Hayden and Rinnyo 1963
Scirpus californicus	Tule, bulrush		In larger, less saline, shoreline pools and freshwater marshes.	Hayden and Rinnyo 1963
Scirpus robustus	Alkali bulrush		Marshes, especially alkali marshes.	Mason 1957; SSA USBR[2] 2000a
Scirpus spp.	Tule, bulrush		Present in many desert waters; planted for waterfowl food in refuge management ponds.	Oglesby pers. obs.
Hydrocharitaceae				
Hydrilla verticillata	Waterweed, water thyme, Florida elodea	I	Noxious invasive weed in Imperial Valley canals and drains. Spreads vegetatively by stem fragments, turions, and tubers. Triploid and hybrid grass carp used for control. Native to Eurasia.	IID PIO[1] 1998; Broussard et al. 2000
Najas marina	Spiny naiad, holly-leaved water nymph		Ponds, lakes	Mason 1957; Hayden and Rinnyo 1963
Juncaceae				
Juncus cooperi	Rush		In larger, less saline, shoreline pools and freshwater marshes; alkaline flats.	Mason 1957; Rowlands 1995b
Juncus torreyi	Rush		Wet places.	Mason 1957
Juncus spp.	Rush		Common in larger, less saline, shoreline pools and freshwater marshes. New and Alamo Rivers, Whitefield Creek, 1000 Palms Oasis.	IID PIO[1] 1998; Oglesby pers. obs.
Lemnaceae				
Lemna spp.	Duckweed		Floating plant in calm waters of drains, springs, streams. Cleveland Street Spillway.	Oglesby pers. obs.

Table V. Continued.

Scientific name	Common name	I**	Notes	Reference
Poaceae				
Arundo donax	Giant reed, "bamboo"	I	Noxious invasive weed forming dense thickets of canes to 10 m tall. Everywhere in low-gradient rivers, drains, streams, springs, and refuge management ponds. Poor wildlife habitat. Rhizomatous. Sterile, spreads easily vegetatively. Native to Eurasia, introduced to CA <1820s. See text.	Broussard et al. 2000; Oglesby pers. obs. See text.
Distichlis spicata	Salt grass		= *D. texana.* Often abundant in water-logged, saline soils near drains, shoreline pools, alkali marshes, springs, palm oases, and seeps. Whitefield Creek. Rhizomatous.	Mason 1957; SSA USBR[2] 2000a; Oglesby pers. obs.
Eriochloa acuminata acuminata	Southwestern cup grass		= *E. gracilis.* Seasonal streams, irrigated fields.	Mason 1957
Eriochloa aristata aristata	Bearded cup grass		Seasonal streams, river banks.	Mason 1957
Eriochloa contracta	Prairie cup grass	I	Irrigated fields.	Mason 1957
Leptochloa filiformis	Red sprangletop	I	Colorado River overflow in Imperial Valley, wet sites, seasonal streams.	Mason 1957
Paspalum dilatatum	Dallis grass	I	Moist places, irrigation ditches. Important forage plant.	Mason 1957
Phragmites australis	Common reed, Carrizo grass, wild cane, canebrake	I?	= *P. communis.* Invasive, often weedy, forming dense thickets in shoreline pools, streams, freshwater and alkali marshes, and refuge waterfowl management ponds. Salt Creek, 1000 Palms. Rhizomatous. Cosmopolitan. Native? See text.	SSA USBR[2] 2000a; Oglesby pers. obs.
Polypogon monspeliensis	Rabbit-foot grass, annual beard-grass	I	Freshwater marshes, streams, ditches, washes. Native to southern and western Europe.	SSA USBR[2] 2000a
Saccharum ravennae	Ravenna grass, plume grass	I	= *Erianthus ravennae.* Stout perennial, up to 4 m tall. Ditches, stream banks. Wister Refuge.	Mason 1957
Sporobolus airoides	Alkali sacaton, dropseed, alkali muhly		= *Muhlenbergia asperifolia.* Seasonally moist alkaline areas, especially fan palm oases, ditches, stream banks.	Mason 1957; Hayden and Rinnyo 1963
	Grass, unidentified	I?	Various species in drains. Whitefield Creek, Cleveland Street Spillway.	Oglesby pers. obs.

Table V. Continued.

Scientific name	Common name	I**	Notes	Reference
Potamogetonaceae				
Potamogeton pectinatus	Sago pondweed, fennel-leaf pondweed		Present in some drains. Important waterfowl food. Both refuges. Cleveland Street Spillway.	Oglesby pers. obs.
Typhaceae				
Typha spp.	Cattail		Often common in shoreline pools, freshwater and alkali marshes at mouths of drains, and waterfowl management ponds. Cleveland Street Spillway, Whitefield Creek, Salt Creek, Red Hill Marina, Alamo and New Rivers. Rhizomatous.	SSA USBR[2] 2000a; Oglesby pers. obs.

Table surely incomplete.
* Taxonomy and biological notes primarily from Hickman (1993); other notes from Mason (1957).
** I: Introduced.
[1] IID PIO: Imperial Irrigation District Public Information Office.
[2] SSA USBR: Salton Sea Authority and US Bureau of Reclamation.

Table VI. Fossil and living aquatic molluscs of the Salton Trough.*

Scientific name	Common name	F, L, or I**	Notes	Reference
Bivalvia				
Corbiculidae				
Corbicula fluminea	Asiatic river clam, Chinese clam	I, L	Widespread in human-modified waters throughout CA and the US, including canals, drains, and reservoirs; not in Salton Sea itself, but in all adjacent agricultural waters. Larvae are brooded on the gills of females and released as young clams. Often a major nuisance, whose filter-feeding can alter ecosystems and food chains, but is an important prey of exotic fishes and raccoons. Introduced ~1950s. Native to East Asia.	Hanna 1966; Taylor 1981; Hornbach 1992; Phelps 1994; Mellink and Ferreira-Bartrina 2000; Oglesby pers. obs.
Sphaeriidae				
Pisidium casteranum	Ubiquitous pea clam	F, L	= *Cyclocalyx*. Cosmopolitan; probably the world's most widespread mollusc; most common *Pisidium* in CA. Lake Cahuilla.	Taylor 1981; Whistler et al. 1995
Unionidae				
Anodonta califoriensis	California floater, swan mussel	F, L	Widespread fossil in Salton Trough; type locality the New River; extinct in southern CA; rare in northern CA. Glochidium larvae parasitic on freshwater fish gills; loss of native fishes may have greatly reduced populations of this species. Lake Cahuilla.	Stearns 1903; Taylor 1981; Whistler et al. 1995; Mellink and Ferreira-Bartrina 2000; Oglesby pers. obs.
Anodonta imbecillus	Paper floater mussel	I	In US portion of lower Colorado River as well as Colorado Delta; may out-compete *A. californiensis*.	Mellink and Ferreira-Bartrina 2000

Table VI. Continued.

Scientific name	Common name	F, L, or I**	Notes	Reference
Gastropoda				
Prosobranchia				
Thiaridae				
Thiara granifera mauiensis		I, L	= *Tarebia.* Often dense populations in springs, canals, drains, and small reservoirs in Coachella and Imperial Valleys. Cleveland Street Spillway, Whitefield Creek, 1000 Palms Oasis. Native to Southeast Asia and Polynesia. See text.	Oglesby 1977, 1993, pers. obs.; Taylor 1981. See text.
Thiara tuberculata		I, L	= *Melanoides.* Often dense populations in springs, canals, drains, and small reservoirs in Coachella and Imperial Valleys. Cleveland Street Spillway, Whitefield Creek. Widely introduced in the Great Basin. Native from Africa to Southeast Asia. See text.	Taylor 1981; Oglesby 1993, pers. obs. See text.
Pulmonata				
Ancylidae				
Ferrissia walkeri	Cloche ancylid	F, L	= *F. californica*? Limpet-shaped; widespread in shallow waters on plant debris. Lake Cahuilla.	Taylor 1981; Whistler et al. 1995
Hydrobiidae				
Amnicola longinquo	Dusky snail, spring-snail	F, L?	Perhaps a species of *Fontelicella,* maybe *F. californiensis.* Lake Cahuilla.	not in Taylor 1981; Whistler et al. 1995
Fontelicella californiensis	Dusky snail, spring-snail	F, L	Southern CA, in muds of springs and seeps. Lake Cahuilla.	Taylor 1981; Whistler et al. 1995
Lithoglyphus sp.	Pebble snail	F	= *Fluminicola.* Taylor (1981) lists two species of *Lithoglyphus,* neither from southern CA. Lake Cahuilla.	not in Taylor 1981; Whistler et al. 1995

Table VI. Continued.

Scientific name	Common name	F, L, or I**	Notes	Reference
Littoridinidae				
Tryonia protea	Desert tryonia	F, L	= *Hydrobia protea,* = *Melania exigua,* = *Pyrgulopsis blakeana,* = *P. cahuillarum.* Widespread fossil in Salton Trough; type locality Colorado Desert; relict living populations restricted to widely scattered Great Basins springs, including three at and near Dos Palmas Oasis east of Salton Sea. Lake Cahuilla.	Stearns 1902; Taylor 1981; Whistler et al. 1995; Oglesby pers. obs.
Physidae				
Physa ampullaria	Pond-snail, paper physa	F, L?	= *Physella.* Is *P. ampullaria* the same species as *P. virgata*? Lake Cahuilla.	not in Taylor 1981; Whistler et al. 1995
Physa virgata	Pond-snail, cork-screw physa	F, L	= *Physella,* = *P. fontinalis,* = *P. humerosa.* Widespread fossil and living snail in Salton Trough and throughout southern CA; common on dense vegetation in slow moving waters. Lake Cahuilla.	Stearns 1903; Taylor 1981; Whistler et al. 1995; Oglesby pers. obs.
Planorbiidae				
Biomphalaria obstructa		I?, L	= *Planorbis gracilentus.* Avenue 82 ditch northwest of Salton Sea; native to Baja California and lower Colorado River including Imperial Valley; Coachella Valley population may be natural range extension or introduction by aquarists. See text.	Basch et al., 1975; Taylor 1981. See text.
Gyraulis parvus	Ash gyro	F, L	Widespread in US and CA; in perennial waters in dense submerged vegetation. Lake Cahuilla.	Taylor 1981; Whistler et al. 1995
Helisoma trivolvus	Ram's horn	F, L?	Perhaps *Planorbella* (*Pierosoma*) *tenuis* (= *Planorbis ammo*). *P. tenuis* is widespread in CA in lakes, ponds, reservoirs, marshes, and slow streams. *P. tenuis* is known from the Colorado Desert. Lake Cahuilla.	not in Taylor 1981; Whistler et al. 1995

* Taxonomy and biology primarily from Taylor (1981).
** F: Fossil in Lake Cahuilla deposits; L: Living; I: Introduced.

Table VII. Non-molluscan aquatic invertebrates of the Salton Trough.*,**

Scientific name	Common name	I***	Notes	Reference
Platyhelminthes				
Digenea				
Paragonimus sp.	Lung fluke	I?	*Thiara granifera* is intermediate host; adults in carnivorous mammals.	Oglesby pers. obs.
Monogenea				
Gyrodactylus imperialis	Monogenetic fluke		Gill parasite on fish.	Kuperman and Matey 2000
Gyrodactylus olsoni	Monogenetic fluke		Gill parasite on longjaw mudsucker.	Kuperman and Matey 2000
Turbellaria	Unidentified free-living turbellarian		Benthic carnivores and scavengers on bacteria, protozoa, algae, small invertebrates.	Kuperman et al. 2000
Nematoda				
Spilophorella sp.	Nematode		Nematodes occur in abundance in benthic bluegreen algal mats and detritus; often rise into the water column when algal mats rise to the surface on their own O_2 production. Nematodes are also found in shoreline pools. Nematode biomass in the Salton Sea is apparently so small as to be ecologically insignificant.	Barlow 1958a; Linsley and Carpelan 1961; Simpson et al. 1998; Kuperman et al. 2000
Monohysteridae	Nematode		Nematodes occur in abundance in benthic bluegreen algal mats and detritus; often rise into the water column when algal mats rise to the surface on their own O_2 production. Nematodes are also found in shoreline pools. Nematode biomass in the Salton Sea is apparently so small as to be ecologically insignificant. The monohysterid was abundant in laboratory microcosms at all salinities through 65 $g\ l^{-1}$.	Barlow 1958a; Linsley and Carpelan 1961; Simpson et al. 1998; Kuperman et al. 2000

Table VII. Continued.

Scientific name	Common name	I***	Notes	Reference
Plectidae	Nematode		Nematodes occur in abundance in benthic bluegreen algal mats and detritus; often rise into the water column when algal mats rise to the surface on their own O_2 production. Nematodes are also found in shoreline pools. Nematode biomass in the Salton Sea is apparently so small as to be ecologically insignificant. The plectid was abundant in laboratory microcosms at all salinities from 30 to 57 g l^{-1}.	Barlow 1958a; Linsley and Carpelan 1961; Simpson et al. 1998; Kuperman et al. 2000
Rotifera				
Brachionus rotundiformis	Planktonic rotifer	I	Formerly lumped with *B. plicatilis*. Abundant in plankton, most numerous in summer. Preyed on by copepods and fish; important in nutrient cycling. See text.	Carpelan 1961d; Kuperman et al. 2000; Oglesby pers. obs.
Synchaeta sp. 1	Benthic rotifer		Benthic. Found at all salinities tested (30 to 65 g l^{-1}) in laboratory microcosms. Distribution in the Salton Sea itself not known.	Tiffany et al. 2000b
Synchaeta sp. 2	Benthic rotifer		Benthic. Found only at 57 and 65 g l^{-1} in laboratory microcosms. Distribution in the Salton Sea itself not known.	Simpson et al. 1998; Tiffany et al. 2000b
Annelida				
Oligochaeta				
Aelosoma sp.	Oligochaete		Described from major canals, but probably much more widespread. Coachella Canal.	Marsh and Stinemetz 1983
Chaetogaster sp.	Oligochaete		Described from major canals, but probably much more widespread. Coachella Canal.	Marsh and Stinemetz 1983
	Oligochaetes, unidentified		Probably widespread. Drains. Cleveland Street Spillway.	Simpson et al. 1998; Oglesby pers. obs.

Table VII. Continued.

Scientific name	Common name	I***	Notes	Reference
Polychaeta				
Nereididae				
Nereis succinea	Pileworm.	I	= *Neanthes.* Planktonic larvae most abundant autumn through spring, lowest density in summer. Benthic, pre-metamorphic juveniles most abundant in winter, but at all times vastly abundant benthic worm, crucial link in food chains leading to sport fish. See text.	Carpelan 1961d; Linsley and Carpelan 1961; Oglesby pers. obs.
Spionidae				
Boccardiella ligerica	Spionid worm	I	= *Boccardia ligerica.* Detritus-feeding polychaete found in "estuarine" locations at Whitewater River, Red Hill Marina, and Alamo River. Widespread in irrigated areas in CA, but not native to this hemisphere. Euryhaline.	Kudenov 1983; J. Setmire pers. comm.; Oglesby pers. obs.
Polydora cornuta	Spionid worm	I	= *P. ligni.* Detritus-feeding polychaete found in mud banks at Alamo River. Native to western North Atlantic. Euryhaline.	J. Carlton, pers. comm.; Oglesby pers. obs.
Streblospio benedicti	Spionid worm	I	Abundant benthic polychaete in Salton Sea. See text.	D. Dexter pers. comm.
Tardigrada	Benthic tardigrade		Herbivore.	Simpson et al. 2000
Crustacea				
Amphipoda				
Corophium louisianum	Amphipod	I	Tiny shoreline amphipod that forms mud tubes; lives in mud, barnacle rubble. Detritus feeder. Introduced from Texas. Red Hill Marina.	Barnard and Gray 1968; Coe et al. 2000; D. Dexter, pers. comm.; Oglesby pers. obs.
Gammarus mucronatus	Amphipod	I	Abundant benthic amphipod at least in shoreline areas, living in algal mats, amongst living and dead barnacles. Food for eared grebes and other invertebrate-feeding birds. See text.	Barnard and Gray, 1969; Oglesby pers. obs.

Table VII. Continued.

Scientific name	Common name	I***	Notes	Reference
Hyalella azteca	Scud		Ubiquitous freshwater amphipod. Cleveland Street Spillway, Whitefield Creek.	Oglesby pers. obs.
Cirripedia				
Thoracica				
Balanus amphitrite amphitrite	Acorn barnacle	I	Pelagic nauplii larvae most abundant January through April. Adults sessile, abundant benthic filter-feeders on any suitable substrate. See text.	Hilton 1945; Linsley and Carpelan 1961; Oglesby pers. obs.
Copepoda				
Cyclopoida				
Apocyclops dengizicus	Cyclopoid copepod	I	= *Cyclops dimorphus*. Abundant in plankton, dominant zooplankter in summer. See text.	Johnson 1953; Carpelan 1961d; Dexter 1993; Oglesby pers. obs.
Harpacticoida				
Cletocamptus deitersi	Harpacticoid copepod	I	Abundant in algae, debris, barnacle sand, and mud. Common in laboratory microcosms above 73 $g \cdot l^{-1}$. Perhaps introduced from Texas with *Halodule wrighti*. Widely distributed in North and Central America, Hawaii, Australia, China, Ethiopia, and Israel in brackish waters in bays, estuaries, salt marshes, and salt and freshwater lakes. Mobile benthic deposit feeder on bluegreens, detritus, and protozoans. Euryhaline, living from 0.5 to 95 $g\ l^{-1}$, reproducing to as high as 80 $g\ l^{-1}$.	Dexter 1995; Hart et al. 1998; Simpson et al. 1998; Kuperman et al. 2000
Nitocra dubia	Harpacticoid copepod		Benthic.	Dexter 1995
Ostracoda				
Cyprides beaconensis	Ostracod		Benthic, living in algal mats and mud. New and Alamo Rivers. See Hammer (1986) for discussions of ostracod biology in other saline lakes.	Kuperman et al. 2000
	Ostracods, unidentified		At least 8 unidentified species known, in relatively small numbers.	Arnal 1961; B. W. Walker 1961; Kuperman et al. 2000; Oglesby pers. obs.

Table VII. Continued.

Scientific name	Common name	I***	Notes	Reference
Decapoda				
Palaemonetes paludosis	Glass shrimp	I	Widespread in rivers, drains, and shoreline pools, often associated with *Enteromorpha.* Hot Mineral Spa drain, Whitefield Creek, Salton Sea. Eaten by bass, sunfish, etc. Native to southeast US. See text.	Hayden and Rinnyo 1963; St. Amant and Day 1972; Oglesby pers. obs.
Procambarus clarkii	Louisiana red crayfish	I	Drains, streams, springs; introduced throughout low-elevation CA. Cleveland Street Spillway, Whitefield Creek, Ciénega de Santa Clara. Native to southeast US. Introduced to all continents, and to lower Colorado River ~1930s. Highly invasive. Omnivorous, reducing aquatic plants, algae, invertebrates, frogs, fish. In some Caribbean islands, eats *Thiara* sp. and other snails; in lab experiments, eats larvae and pupae of malarial mosquitoes, *Anopheles* spp. Eaten by larger exotic fish, soft-shell turtles, garter snakes, rails, and some mid-sized mammals. More euryhaline than usually believed.	Hofkin et al. 1991, 1992; Newsom and Davis 1994; Hunter and Lindqvist 1995; Mkoji et al. 1999; Mellink and Ferreira-Bartrina 2000; Oglesby pers. obs.
Insecta				
Coleoptera				
Dytiscidae	Predaceous water beetle, unidentified		Carnivorous swimming beetle; all stages aquatic, but adults can fly. Drains and pools. San Sebastian Marsh, Cleveland Street Spillway.	Lebo et al 1982; Oglesby pers. obs.
Staphylinidae				
Bledius ferratus	Rove beetle		Tiny, often wingless as adults; more likely to be marginal in damp soil than aquatic. Salt marshes.	Moore and Legner 1973
Cafius sulcicollis	Rove beetle		Tiny, often wingless as adults; more likely to be marginal in damp soil than aquatic; drains. Desert Shores.	Moore and Legner 1973
Chironomidae	Non-biting midge, unidentified chironomid larvae		Larvae often abundant in benthic algae and detritus; important as prey for fish, shorebirds, and insects. Some species euryhaline, from 4 g l^{-1} to at least 33 g l^{-1} at the Salton Sea. Drowned fields, blue-green algal mats, drains, springs, streams, pools. San Sebastian Marsh, Cleveland Street Spillway, Whitefield Creek.	Lothrop and Mulla, 1995; Oglesby pers. obs.

Table VII. Continued.

Scientific name	Common name	I***	Notes	Reference
Culicidae				
Culex tarsalis	Mosquito		Larvae ("wrigglers") ecologically important as prey for fish, birds, and insects. Only adult females bite humans; adult males feed on plants. Drains, marshes, pools. See text.	Reisen and Lothrop 1995; Reisen et al. 1995, 1998
Aëdes dorsalis	Mosquito		Larvae ("wrigglers") ecologically important as prey for fish, birds, and insects. Only adult females bite humans; adult males feed on plants. Drains, marshes, pools. See text.	Reisen et al. 1998
Anopheles spp.	Malarial mosquito		Widespread in CA and probably Salton Trough. Larvae ("wrigglers") ecologically important as prey for fish, birds, and insects. Only adult females bite humans; adult males feed on plants. Drains, marshes, pools. See text.	Mullens and Dada 1992; Reisen et al. 1999.
	Mosquito, unidentified larvae and pupae		Larvae ("wrigglers") ecologically important as prey for fish, birds, and insects. Only adult females bite humans; adult males feed on plants. Drains, marshes, pools. San Sebastian Marsh, Cleveland Street Spillway, Whitefield Creek. See text.	Lebo et al. 1982; Oglesby pers. obs.
Ephydridae				
Ephydra riparia	Brine fly		Larvae benthic in shallow waters, often abundant. Adults aerial, but usually rest on plants or wet soil. Detritivores and herbivores, particularly on Cyanobacteria. Along Salton Sea shoreline and in pools. Whitefield Creek. *E. riparia* is Holarctic and most widespread species in genus. See text.	Barlow 1958a; Simpson et al. 1998; Oglesby pers. obs. See text.
Heleidae				
Dasyhelea sp.	Biting midge, sand fly		Larvae live in and feed on bluegreen algal mats. Adult females suck mammalian and avian blood. Pools, smaller drains. San Sebastian Marsh.	Barlow 1958a; Lebo et al. 1982

Table VII. Continued.

Scientific name	Common name	I***	Notes	Reference
Leptoconops terrens	Black gnat		Larvae live in and feed on bluegreen algal mats. Adult females suck mammalian and avian blood. Pools, smaller drains. San Sebastian Marsh.	Lebo et al. 1982
Tabanidae				
Tabanus punctifer	Big black horsefly		Larvae predaceous on soft-bodied invertebrates. Adult females are vicious biters of birds and mammals, including humans, feeding on blood; adult males feed on plants. Drains, pools, springs, streams. San Sebastian Marsh, Cleveland Street Spillway, Whitefield Creek.	Lebo et al. 1982; Oglesby pers. obs.
Ephemeroptera	Mayfly, unidentified		Detritus-feeding nymphs are important prey in aquatic systems. Adults do not feed. San Sebastian Marsh, Cleveland Street Spillway.	Lebo et al. 1982; Oglesby pers. obs.
Hemiptera				
Belostomatidae	Giant water bug, toe biter, fish killer, unidentified		All life cycle stages aquatic, though adults can fly. All stages predaceous, lurking in detritus and vegetation. Drains. Cleveland Street Spillway.	Oglesby pers. obs.
Corixidae				
Trichocorixa reticulata	Water boatman		= *T. verticalis saltoni*, = *T. verticalis interiores*. Species widely distributed in western hemisphere; all life cycle stages aquatic, though adults can fly. Herbivores, detritivores, microcarnivores. Important prey for fish, birds, insects. Often abundant along Salton Sea shoreline, hard substrates, shoreline pools, mud pot pools. San Sebastian Marsh, Cleveland Street Spillway, Whitefield Creek. Very euryhaline. See text.	Lebo et al. 1982; Oglesby pers. obs. See text.

Table VII. Continued.

Scientific name	Common name	I***	Notes	Reference
Gerridae				
Gerris remigis	Water strider		Species common in all of North America. All life cycle stages live on top of water surface, are predators of insects at the water surface such as mosquito wrigglers. Adults winged, but rarely fly. Cleveland Street Spillway, Whitefield Creek.	Oglesby pers. obs.
Notonectidae	Back swimmer, unidentified		All stages aquatic, fierce predators. Adults fly readily. Drains, pools. San Sebastian Marsh.	Lebo et al. 1982
Veliidae	Small water strider, unidentified		All life cycle stages live on water surface, predators of insects at the water surface such as mosquito wrigglers; adults winged. Drains. Cleveland Street Spillway.	Oglesby pers. obs.
Lepidoptera				
Pyralidae				
Parargyractis confusalis	Aquatic moth		Larvae herbivorous on aquatic algae, building silken tents on rocks in the water. Adults aerial and fly; females enter the water to oviposit under rocks. Coachella Canal.	Marsh and Stinemetz 1983
Odonata				
Anisoptera				
Gomphidae	Dragonfly, unidentified		Nymphs lurking predators on sandy bottoms of shallow waters. Adults mostly sedentary, making short predatory flights. San Sebastian Marsh.	Lebo et al. 1982
Libellulidae				
Libellula saturata	Red skimmer		Species widespread in CA. Nymphs lurking predators in detritus and vegetation. Adults territorial and patrol shorelines for insect prey. Cleveland Street Spillway, Whitefield Creek.	Oglesby pers. obs.

Table VII. Continued.

Scientific name	Common name	I***	Notes	Reference
Zygoptera				
Coenagrionidae				
Nehalennia sp.	Damselfly		Nymphs lurking predators. Adults aerial predators on insects. Cleveland Street Spillway, Whitefield Creek, Red Hill Marina.	Oglesby pers. obs.
	Damselfly, unidentified nymphs and adults		Nymphs lurking predators. Adults aerial predators on insects. Cleveland Street Spillway, Whitefield Creek.	Oglesby pers. obs.
Trichoptera				
Hydropsychidae				
Smicridea utico	Caddisfly		Larvae live in cases, feed on detritus and small algae. Adults aerial. This species is known only from Imperial County. Coachella Canal.	Marsh and Stinemetz 1983
	Caddisfly, unidentified larvae		Larvae live in cases, feed on detritus and small algae. Adults aerial. Cleveland Street Spillway, Whitefield Creek.	Oglesby pers. obs.

Table surely incomplete.
* Most biological information comes from Usinger (1968) and Oglesby pers. obs.
** For Molluscs, see Table VI.
*** I: Introduced.

Table VIII. Fish of the Salton Trough.*

Name	Common name	I**	Notes	Reference
Catostomidae				
Xyrauchen texanus	Humpback sucker, razorback sucker		Endangered (federal, state); least rare of Colorado River mainstream endemics. Occasionally found in Imperial Valley canals and drains, and Colorado Delta. Juveniles preyed upon by green sunfish and catfish. See text.	Moyle 1976; Imperial Irrigation District 1994; Pister 1995; Mellink and Ferreira-Bartrina 2000
Centrarchidae				
Archoplites interruptus	Sacramento perch	I	Ramer Lake. Very euryhaline, tolerant of alkaline conditions. Native to northern CA and the Central Valley, the only centrarchid native to CA.	Moyle 1976; Swift et al. 1993
Lepomis cyanellus	Green sunfish	I	Widely distributed in Imperial and Coachella Valley canals and drains. Native to Mississippi drainage, introduced all over world. Undesirable introduction.	Moyle 1976; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997
Lepomis macrochirus	Bluegill	I	Widely distributed in canals and drains. Native to eastern North America, introduced all over world. Popular game fish.	Hayden and Rinnyo 1963; Black 1980; Dill and Cordone 1997
Pomoxis annularis and/or *P. nigromaculatus*	Crappie	I	Widely distributed in canals and drains. Native to eastern North America, introduced all over world. Small game fish.	Hayden and Rinnyo 1963; Feldmeth 1980; Swift et al. 1993; Dill and Cordone 1997
Micropterus salmoides	Largemouth bass	I	Widely distributed in canals and drains. New and Alamo Rivers. Native to eastern North America, introduced all over world. Very popular game fish.	Moyle 1976; Feldmeth 1980; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997

Table VIII. Continued.

Name	Common name	I**	Notes	Reference
Cichlidae				
Oreochromis mossambicus	California Mozambique tilapia	I	One of the two most widely introduced fish species in the world. Legal in CA. Imperial and Coachella Valley drains and canals, New River, most aquaculture ponds, Ciénega de Santa Clara. Vastly abundant in Salton Sea. Native to Africa, but introduced from Java by way of AZ. Euryhaline. See text.	St. Amant 1966; Mearns 1975; Moyle 1976; Schoenherr 1979; Feldmeth 1980; Swift et al. 1993; Imperial Irrigation District 1994; Costa-Pierce and Doyle 1997; Dill and Cordone 1997; Mellink and Ferreira-Bartrina 2000.
Tilapia zillii	Zill's tilapia, redbelly tilapia	I	Legal in CA. Imperial and Coachella Valley drains and canals, New River, wetlands near Salton Sea, apparently no longer in Salton Sea, Ciénega de Santa Clara. Native to Africa but introduced from AZ by way of Israel. Experts encourage total eradication. Euryhaline. See text.	Mearns 1975; Moyle 1976; Schoenherr 1979; Feldmeth 1980; Swift et al. 1993; Costa-Pierce and Doyle 1997; Dill and Cordone 1997; Mellink and Ferreira-Bartrina 2000
Clupeidae				
Dorosoma petenense	Threadfin shad	I	Migratory in Imperial Valley drains and canals. Salton Sea. Native to streams flowing into Gulf of Mexico from the southern Mississippi River system to Belize. Euryhaline. See text.	Moyle 1976; Schoenherr 1979; Swift et al. 1993; Dill and Cordone 1997
Cyprinidae				
Carassius auratus	Goldfish	I	Widely distributed in canals and drains. Native to Asia.	Pister 1995; Dill and Cordone 1997
Ctenopharyngodon idella	Triploid grass carp	I	Stocked. Widely distributed in canals and drains. See text.	Moyle 1976; Swift et al. 1993; Dill and Cordone 1997
Ctenopharyngodon idella × *Hypophthalmichthys nobilis*	Grass carp × bighead carp hybrid	I	Stocked, not apparently locally reproducing. Distributed in canals and drains.	Swift et al. 1993; Dill and Cordone 1997

Table VIII. Continued.

Name	Common name	I**	Notes	Reference
Cyprinella lutrensis	Red shiner, Redfin shiner	I	= *Notropis*. Widely distributed in Coachella and Imperial Valley canals and drains. Alamo and Whitewater Rivers, Ciénega de Santa Clara. Native to Mississippi and Rio Grande river systems. A bait fish with a negative effect on native fishes.	Mearns 1975; Moyle 1976; Schoenherr 1979; Feldmeth 1980; Imperial Irrigation District 1994; Dill and Cordone 1997; Mellink and Ferreira-Bartrina 2000
Cyprinus carpio	Carp	I	One of the two most widely introduced fish species in the world. Common in Imperial and Coachella Valley canals and drains, Alamo and New Rivers, Ciénega de Santa Clara. Often abundant. Native to Asia.	Moyle 1976; Schoenherr 1979; Feldmeth 1980; Imperial Irrigation District 1994; Dill and Cordone 1997; Mellink and Ferreira-Bartrina 2000; Oglesby pers. obs.
Lavinia exilicauda	Hitch	I	Ramer Lake. Native to northern CA.	Swift et al. 1993
Notemigonus chrysoleucus	Golden shiner	I	Coachella Valley drains. Native to eastern North American and Mississippi River systems.	Moyle 1976; Schoenherr 1979; Dill and Cordone 1997
Cyprinodontidae				
Cyprinodon macularius	Desert pup-fish		Endangered (federal, state). Rare in Imperial and Coachella Valley canals and drains, springs, shoreline pools. Salt Creek, Whitefield Creek, Cleveland Street Spillway, Dos Palmas Oasis, 1000 Palms Oasis, San Sebastian Marsh, Salton Sea shoreline, Ciénega de Santa Clara and other places in the Colorado River delta. Very euryhaline. See text.	Walker et al. 1961a; Mearns 1975; Moyle 1976; Schoenherr 1979; Feldmeth 1980; Swift et al. 1993; Imperial Irrigation District 1994; Mellink and Ferreira-Bartrina 2000; A. Schoenherr pers. comm.; Oglesby pers. obs.
Elopidae				
Elops affinis	Machete, tenpounder		A carnivorous coastal game fish feeding on crustaceans and small fish. Normally found in inshore waters, but is euryhaline and can be migratory. Machetes were common in the early Salton Sea, dying out either because of dam construction or high salinity. There are reports of machetes in the lower Colorado River in the late 1990s. See text.	Dill and Woodhill 1942; Walker et al. 1961a; Bettaso and Young 1999; Mellink and Ferreira-Bartrina 2000

Table VIII. Continued.

Name	Common name	I**	Notes	Reference
Gobiidae				
Gillichthys mirabilis	Longjaw mudsucker	I	Present in mouths of Imperial and Coachella Valley drains, Salton Sea. Native to Pacific Coast from Bahía Magdalena in Baja California to north of San Francisco Bay, and northern Gulf of California; introduced from San Diego Bay. Euryhaline. See text.	Walker et al. 1961a; Schoenherr 1979; Imperial Irrigation District 1994
Ictaluridae				
Ameiurus natalis	Yellow bullhead	I	= *Ictalurus.* Widely distributed in Imperial Valley drains and canals. Salt Creek, New River. Native to eastern US east of Rocky Mountains.	Black 1980; Imperial Irrigation District 1994; Dill and Cordone 1997
Ameiurus nebulosus	Brown bullhead	I	= *Ictalurus.* Widely distributed. Native to US east of Mississippi River. Popular game fish.	Moyle 1976; Schoenherr 1979; Dill and Cordone 1997
Ictalurus punctatus	Channel catfish	I	Widely distributed. New and Alamo Rivers, Ciénega de Santa Clara. Native to Mississippi River system south into México. Popular game fish.	Moyle 1976; Schoenherr 1979; Imperial Irrigation District 1994; Dill and Cordone 1997; Mellink and Ferreira-Bartrina 2000
Pylodictis olivaris	Flathead catfish	I	Widely distributed. In Imperial Valley, preys on endangered *Xyrauchen texanus* and other fish. New River. Native to Rio Grande and Mississippi River systems into México. Desirable trophy fish.	Moyle 1976; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997
Mugilidae				
Mugil cephalus	Striped mullet, gray mullet		Very euryhaline, catadromous, migrating from freshwaters to estuaries to breed. Never bred in Salton Sea. Now rare in Salton Sea and lower Colorado River, but reports persist. Present in Colorado River delta, Ciénega de Santa Clara. Cosmopolitan in tropical and subtropical waters. Euryhaline. See text.	Hendricks 1961b; Walker et al. 1961a; Moyle 1976; Bettaso and Young 1999; Mellink and Ferreira-Bartrina 2000

Table VIII. Continued.

Name	Common name	I**	Notes	Reference
Poeciliidae				
Gambusia affinis	Mosquitofish	I	Widely distributed throughout Imperial and Coachella Valleys. Alamo and New Rivers; very common along shoreline of Salton Sea, Ciénega de Santa Clara. Native to eastern US. Euryhaline. Livebearer. See text.	Barlow 1958a; Walker et al. 1961a; Mearns 1975; Moyle 1976; Schoenherr 1979; Feldmeth 1980; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997; Mellink and Ferreira-Bartrina 2000; Oglesby pers. obs.
Poecilia latipinna	Sailfin molly	I	Widely distributed in Imperial and Coachella Valley drains and canals. New and Alamo Rivers; very common along shoreline of Salton Sea, Ciénega de Santa Clara. Native to coastal North America from South Carolina to northeastern México. Euryhaline. Sometimes used as corvina bait. Livebearer. See text.	Barlow 1958a, 1963; Whitney 1961b; Barlow and De Vlaming 1972; Mearns 1975; Courtois 1976; Moyle 1976; Loretz 1979; Schoenherr 1979; Feldmeth 1980; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997; Mellink and Ferreira-Bartrina 2000; Oglesby pers. obs.
Poecilia mexicana	Shortfin molly	I	Coachella and Imperial Valley drains and canals. Native to México and northern South America. Livebearer.	St. Amant and Sharp 1971; Mearns 1975; Moyle 1976; Schoenherr 1979; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997

Table VIII. Continued.

Name	Common name	I**	Notes	Reference
Poecilia sphenops	Liberty molly	I	Probably a misidentification for *P. mexicana.* Some Coachella Valley canals. Native to southern US to Central America. Livebearer.	Schoenherr 1979; Dill and Cordone 1997
Poeciliopsis gracilis	Porthole fish; porthole livebearer	I	Widely distributed in Imperial and Coachella Valley drains and canals. Native to Central America and southern México. Livebearer.	Mearns 1975; Schoenherr 1979; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997
Xiphophorus helleri	Green swordtail	I	Coachella Valley drains. Native to northern South America. Livebearer.	Schoenherr 1979; Dill and Cordone 1997
Xiphophorus variatus	Variable platy	I	Coachella Valley drains. Native to México and Central America. Rare or extinct in Salton Trough. Livebearer.	St. Amant and Sharp 1971; Mearns 1975; Moyle 1976; Schoenherr 1979; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997
Pomadysidae				
Anisotremus davidsoni	Sargo	I	Abundant in Salton Sea. Native to Gulf of California. See text.	Walker et al. 1961a
Rivulidae				
Rivulus harti	Trinidad or giant rivulus	I	Drains. Rare. Native to Colombia and Venezuela.	Swift et al. 1993; Dill and Cordone 1997
Sciaenidae				
Bairdiella icistia	Bairdiella, Gulf croaker	I	Present in mouths of Imperial and Coachella Valley drains and rivers. Abundant in Salton Sea. Native to Gulf of California. See text.	Whitney 1961a; Schoenherr 1979; Swift et al. 1993; Imperial Irrigation District 1994; Dill and Cordone 1997

Table VIII. Continued.

Name	Common name	I**	Notes	Reference
Cynoscion nobilis	White sea bass	I	= *Atractoscion*. Present in mouths of Imperial and Coachella Valley drains and rivers. Native to Pacific Coast from Juneau to Cabo San Lucas, Baja California, and Gulf of California.	Schoenherr 1979
Cynoscion xanthulus	Orangemouth corvina	I	Present in mouths of Imperial and Coachella Valley drains and rivers. Abundant in Salton Sea. Native to Gulf of California. See text.	Whitney 1961b; Lasker et al. 1972; Imperial Irrigation District 1994; Dill and Cordone 1997

Table surely incomplete for "freshwater" fish in canals, drains, streams.
* Taxonomy and biology primarily from Moyle (1976).
** I: Introduced.

Table IX. Aquatic amphibians, reptiles, and mammals of the Salton Trough.*

Name	Common name	I**	Notes	Reference
Amphibia				
Aura				
Bufo alvarius	Sonoran Desert toad		Lower Colorado River and Colorado delta into Sonora. Nearly extinct in Salton Trough and delta, apparently due to bullfrogs.	Stebbins 1985; Mellink and Ferreira-Bartrina 2000
Bufo cognatus	Great plains toad		Springs, streams, canals, drains, Colorado delta; common in irrigation channels. Cleveland Street Spillway.	Stebbins 1985; Mellink and Ferreira-Bartrina 2000; W Wirtz pers. comm.; Oglesby pers. obs.
Bufo microcephalus californicus	Arroyo southwestern toad		Federally Endangered; CA Species of Concern. Restricted to rivers with shallow, gravel pools adjacent to sandy terraces. Extirpated from Salton Trough except for a small population near Bonniebelle.	Salton Sea Authority and US Bureau of Reclamation 2000a
Bufo punctatus	Spotted toad, red-spotted toad		Springs, streams, canals, drains, Colorado delta. Cleveland Street Spillway.	Stebbins 1985; Mayhew 1995; Mellink and Ferreira-Bartrina 2000; Oglesby pers. obs.
Bufo woodehousei	Woodehouse toad		Increasingly rare; formerly in San Sebastian Marsh. Still in Colorado delta.	Lebo et al. 1982; Stebbins 1985; Mellink and Ferreira-Bartrina 2000
Bufo sp.	Toad tadpoles, unidentified		Springs, streams, canals, drains.	Oglesby pers. obs.
Hyla regilla	Pacific tree frog		Springs, streams, canals, drains. San Sebastian Marsh.	Lebo et al. 1982; Stebbins 1985
Rana aurora draytoni	California red-legged frog		Federally threatened. Adults require dense riparian vegetation associated with deep, slow or still water. Probably extirpated from Salton Trough and southern CA.	Salton Sea Authority and US Bureau of Reclamation 2000a
Rana berlandieri	Rio Grande leopard frog	I	Recently introduced into Salton Trough in both México and US; present in Colorado River delta.	Mellink and Ferreira-Bartrina 2000
Rana catesbeiana	Bullfrog	I	Very widespread in drains, canals, springs, streams, and marshes. Aggressive generalist predator and competitor on native amphibians and fish. Native to southeast US. See text.	Stebbins 1985; Oglesby pers. obs. See text.

Table IX. Continued.

Name	Common name	I**	Notes	Reference
Rana yavapaiensis	Lowland leopard frog		Federal and CA Species of Concern. Very rare; still occurs in AZ and Colorado delta. Extinct and undescribed San Sebastian Marsh leopard frog may be this species. Remarkably salt tolerant. *R. yavapaiensis* uses permanent pools, side streams of main river channels, and overflow ponds. *Rana catesbeiana* and/or *R. berlandieri* may be responsible for population decline.	Ruibal 1959, 1963 as *R. pipiens*; Stebbins 1985; Mayhew 1995; Mellink and Ferreira-Bartrina 2000; Salton Sea Authority and US Bureau of Reclamation 2000a
Scaphiopus couchi	Western spadefoot toad		CA Species of Concern. Restricted to east side of Algodones Dunes. Perhaps formerly in Colorado Delta. Usually buried, brought to surface to urinate, rehydrate, breed, and feed by sound of summer thunderstorms, and by off-road vehicle noise any time of year. Population in serious decline.	Mayhew 1995; Brattstrom and Bondello 1995; Mellink and Ferreira-Bartrina 2000
Urodela				
Ambystoma tigrinum	Tiger salamander	I	Used as bait, often released in fishing areas. Two specimens known from Yuma AZ. Larvae compete with those of native amphibians.	Mellink and Ferreira-Bartrina 2000
Batrachoseps aridus	Desert slender salamander		Federally and CA Endangered. Under limestone slabs and talus in fan palm oases on moist canyon bottoms. One known population, at Hidden Palms.	Mayhew 1995; Salton Sea Authority and US Bureau of Reclamation 2000a
Reptilia				
Chelonia				
Chrysemys picta	Painted turtle	I	Recently reported in Mexican portion of Colorado delta and southwest CA. Surely derived from released pets.	Mellink and Ferreira-Bartrina 2000
Kinosternon sonoriensis	Sonoran mud turtle		Lower Colorado River, apparently not in México.	Mellink and Ferreira-Bartrina 2000
Trionyx spiniferus emoryi	Spiny soft-shelled turtle	I	= *Apalone*. Canals, drains. Native to southeast US and Rio Grande system, introduced to Salton Trough ~1900s. Much reduced in Colorado delta due to hunting for food.	Stebbins 1985; Mellink and Ferreira-Bartrina 2000; W. Wirtz pers. comm.

Table IX. Continued.

Name	Common name	I**	Notes	Reference
Crocodilia				
Alligator mississippiensis	American alligator	I	Released several times in 1930s and 1940s into US portion of the lower Colorado River, from a traveling zoo, as well as released pets. There is a Rancho El Caiman on the Río Pescadero.	Mellink and Ferreira-Bartrina 2000
Serpentes				
Thamnophis marcianus	Checkered garter snake		Riparian areas and agricultural ditches. Rare and declining due to habitat loss. Coachella Valley canals, drains, Colorado delta.	Stebbins 1985; Mellink and Ferreira-Bartrina 2000; A. Schoenherr, pers. comm.; Oglesby pers. obs.
Mammalia				
Carnivora				
Lutra canadensis	River otter		Abundant in Valle de Mexicali in 1800s, major decline in 1900s. Present in Río Hardy up to 1955. May be extirpated.	Mellink and Ferreira-Bartrina 2000
Rodentia				
Castor canadensis	Canadian beaver		Formerly abundant along lower Colorado River, populations much reduced in México. Large population fluctuations relating to water levels in Colorado delta.	Mellink and Ferreira-Bartrina 2000
Ondatra zibethicus bernardi	Muskrat		Large population fluctuations. Nests in burrows in mud banks. Primarily Imperial Valley and Colorado delta. Springs, streams, canals, drains. Whitewater Creek, Cleveland Street Spillway.	Mellink 1995; Yohe 1998; Mellink and Ferreira-Bartrina 2000; W. Wirtz. pers. comm.; Oglesby pers. obs.

* Taxonomy and biology primarily from Stebbins (1985).
** I: Introduced.

Table X. Endangered, threatened, rare, and sensitive birds of the Salton Trough.

Scientific name	Common name	Status*	Breeding status**	Notes
Podicepiformes				
Podiceps nigrocollis	Eared grebe	F: – CA: SpC	B+, C	Overwinters on Salton Sea in large numbers, supplemented by spring migrants: as many as 3–4 million—up to 90% of the entire world's population of this species. Summer grebes common, especially near river mouths. Feeds on benthic invertebrates. See text.
Pelecaniformes				
Pelecanus erythrorhynchos	American white pelican	F: – CA: SpC	xB, C	One of the first species to breed at new Salton Sea after 1907. Bred on Salton Sea islets until 1957. Overwinters in moderate numbers; most common in spring and fall (up to 33,000); a few summer. Gregarious. Piscivore on open water of Salton Sea and near inlets, feeding from water surface, usually in synchronized groups. See text.
Pelecanus occidentalis	Brown pelican	F: E CA: E	B+, S, C	Disperses into Salton Trough after breeding in Gulf of California; some overwintered beginning in 1987; began breeding in 1996, at Alamo River delta. Gregarious. Year-round population ~5000. Piscivore on open water of Salton Sea, plunge-diving from 10 to 13 m. See text.
Phalacrocorax auritus	Double-crested cormorant	F: – CA: SpC	B, S, C	Resident, with up to ~10,000 present. One of the first species to breed at new Salton Sea after 1907. Sporadic nesting with markedly variable reproductive success; breeding colony on Mullet Island had 4500 nests in 1999, the largest colony in CA. Gregarious. Piscivore on Salton Sea, inlets, and lakes, catching fish by swimming under water. See text.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Ciconiiformes				
Botaurus lentiginosus	American bittern	F: SpC CA: –	B+, S	Transient and rare summer breeder in dense cattail and tule marshes; most summer birds are nonbreeders. Secretive. Feeds on fish and aquatic invertebrates.
Ixobrychus exilis hesperis	Western least bittern	F: SpC CA: SpC	B, R, S	Breeds in dense cattail and tule marshes; most common in summer, but present year-round. Secretive. Estimated ~550 birds in Salton Trough. Feeds on fish and aquatic invertebrates.
Ardea herodias	Great blue heron	F: – CA: SpC	B, S, R, C	One of first species to breed at new Salton Sea after 1907. Resident and common winter and migratory heron, but some present in summer; breeding colonies in decline. Nests in snags. Feeds on fish, amphibians, and small birds.
Ardea alba	Great egret	F: – CA: SpC	B, S, R, C	Common winter and migratory egret; breeds, but colonies are in decline. Nests in snags. Feeds on fish, amphibians, and small birds.
Egretta rufescens	Reddish egret	F: SpC CA: –		Rare visitor in summer and fall, dispersing northwards after breeding in México.
Plegadis chihi	White-faced ibis	F: SpC CA: SpC	B+, R	Salton Trough is the major wintering site in West, with up to 24,000 present; small numbers breed sporadically since late 1950s; breeding population began increasing in 1970s. Nests in dense, tall marshes. Gregarious. Probe feeder on invertebrates in irrigated fields and freshwater marshes. Has high concentrations of DDT and its metabolites.
Mycteria americana	Wood stork	F: – CA: SpC		Disperses into southern Salton Trough after breeding in Gulf of California; up to ~1000 birds formerly present, now usually ~100. Gregarious. Declining. Pick and probe piscivore at edge of Salton Sea and in marshes, especially in Imperial Valley.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Anseriformes				
Dendrocygna bicolor	Fulvous whistling duck	F: SpC CA: SpC	xB, B+	Present year-round in Imperial Valley, but largest numbers (~200) in summer; ~5 breeding pairs. More abundant in Colorado delta, but not in Valle de Mexicali. Nocturnal, so status difficult to determine. Gregarious. Declining in US and México. Feeds on vegetation in irrigated fields and dense marshes.
Branta canadensis leucopareia	Aleutian Canada goose	F: T CA: –		Winters in very small numbers; other subspecies much more common. Gregarious. Feeds on grain and insects in fields, marshes, and refuges.
Falconiformes				
Pandion haliaetus	Osprey	F: – CA: SpC		Rare vagrant at any time of the year, more common in spring and fall. Piscivore on open water of Salton Sea, inlets, and lakes.
Haliaeëtus leucocephalus leucocephalus	Bald eagle	F: T CA: E		Winters regularly in very small numbers. Piscivore and kleptoparasite on Salton Sea and larger adjacent waters and ponds; a pest in aquaculture ponds.
Circus cyaneus	Northern harrier, marsh hawk	F: – CA: SpC	B+	Winters in moderate numbers; rare breeder, nesting on the ground in marshes. Feeds on small vertebrates and insects in irrigated fields and marshes.
Accipiter striatus	Sharp-shinned hawk	F: – CA: SpC	B+	Resident and migrant in small numbers. Very rare breeder. Feeds on small birds in scrub and woodland habitats.
Accipiter cooperi	Cooper's hawk	F: – CA: SpC	xB or B+	Winters in small numbers, but can be found year-round. Very rare breeder. Nests in trees, often near riparian areas. Feeds on small birds and mammals in scrub and deciduous riparian habitats.
Accipiter gentilis	Northern goshawk	F: SpC CA: SpC		Very rare winter visitor. Feeds on ducks and ground-dwelling birds.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Buteo swainsoni	Swainson's hawk	F: – CA: T		Rare spring and even rarer fall migrant. Insectivore in open fields, but also feeds on small vertebrates.
Buteo regalis	Ferruginous hawk	F: SpC CA: SpC		Winters in small numbers, often roosting on the ground. Feeds on small mammals in open fields.
Parabuteo unicinctus	Harris' hawk	F: – CA: SpC	xB	Present in very small numbers fall and winter. Formerly bred in Imperial Valley; a released pair bred there in 1976. Prefers riparian woodland (cottonwoods) adjacent to open fields.
Aquila chrysaetos	Golden eagle	F: – CA: SpC	B	Small numbers resident and breeding in local mountains. Feeds and scavenges on mammals and birds in open, usually mountainous country.
Falco columbarius	Merlin	F: – CA: SpC		Rare fall and winter visitor.
Falco peregrinus anatum	Peregrine falcon	F: delisted 8/1999 CA: E	B	Rare vagrant any time of year, primarily winter. Feeds on small birds, such as shorebirds and ducks on Salton Sea and adjacent fields and marshes.
Falco americanus	Prairie falcon	F: – CA: SpC		A few winter; occasional other times of year, ~30 birds at most. Feeds on small vertebrates in fields, marshes, and over Salton Sea.
Gruiformes				
Laterallus jamaicensis coturniculus	California black rail	F: SpC CA: T	B, R	Resident of dense cattail and tule marshes, especially along All-American and Coachella Canals; lining these canals eliminates marshes and rails. Also at Finney and Ramer Lakes, Salt Creek, San Sebastian Marsh, and seeps. Individual populations small, variable, and highly sensitive to marsh modification. Extremely secretive. Feeds on invertebrates.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Rallus longirostris yumanensis	Yuma clapper rail	F: E CA: T	B, R	Resident of dense freshwater and brackish cattail, tule, and *Phragmites* marshes, particularly in the Wister state refuge in Imperial Valley; more common in summer (~400 birds, ~40% of the entire population of this subspecies). 50% of population in Ciénega de Santa Clara. Secretive. Feeds on invertebrates (molluscs, crustaceans) and occasionally small fish, mammals, and plants. See text.
Grus canadensis tabida	Greater sandhill crane	F: – CA: T		Several hundred winter south of Brawley in Imperial Valley irrigated fields. Gregarious. Feeds on seeds, other vegetation, occasionally on insects and amphibians in agricultural fields and marshes. *G. canadensis canadensis* may also be present.
Charadriiformes				
Charadrius alexandrinus nivosus	Western snowy plover	F: T CA: SpC	B, S, C	Resident, supplemented by summer migrants. Breeds: >200 birds, the largest breeding colony in interior CA (Page et al. 1991; Friend 1999); largest wintering population in interior CA. Nests are scrapes on dry sand. Pick-up feeder on dry sand and gravel beaches, rarely in shallow water. See text.
Charadrius montanus	Mountain plover	F: proposed T CA: SpC		One of the largest wintering populations (7,000 to 10,000) on Pacific Flyway, chiefly in Imperial Valley; also spring and fall migrant. Gregarious. Pick-up feeder on insects in irrigated and sometimes dry fields.
Numenius americanus	Long-billed curlew	F: proposed E CA: SpC		Found nearly year-round; most common in winter. Probe feeder on invertebrates in grain fields, mud flats, and shallow water.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Larus atricilla	Laughing gull	F: – CA: SpC	xB	Common post breeding (2000) in summer; has bred in the past (first breeding record in 1920s), but no evidence for current breeding. Scavenges along Salton Sea shoreline, and forages for invertebrates and fish.
Larus californicus	California gull	F: – CA: SpC	B, S, C	On California list because of reduced population at main CA breeding colonies on islets on Mono Lake.
Sterna nilotica vanrossemi	Van Rossem's gull-billed tern	F: SpC CA: SpC	B, S, C	Salton Sea first breeding site (1927) in western US, now larger of only two colonies in the West (the other in San Diego Bay). Present year-round; most abundant summer. Feeds on small invertebrates over irrigated fields and fish on open water of Salton Sea, inlets, and rivers; dives for fish and hawks insects on the wing.
Sterna elegans	Elegant tern	F: SpC CA: –	B, S, C	Resident. Dives for fish.
Sterna antillarum browni	California least tern	F: E CA: E	B+, S, C	Summer visitant, but can be present any time of year. Piscivore on open water of Salton Sea, inlets, and rivers. Dives for small fish and crustaceans.
Chilodonias niger	Black tern	F: SpC CA: SpC		Spring and fall migrant; a few overwinter; usually abundant in summer but no evidence of breeding. Salton Sea is a crucial fall staging area. Hawks insects on the wing over open fields and plucks them from plants, more rarely feeding on fish and other small aquatic animals in Salton Sea.
Rhynchops nigra	Black skimmer	F: – CA: SpC	B, S, C	First Salton Sea record 1968; first bred 1972; breeding population ~600, usually the largest colony in CA. Present from spring through autumn; does not winter. Gregarious. Piscivore on open water of Salton Sea and rivers, fishing with lower, longer bill in the water while flying. See text.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Cuculiformes				
Coccyzus americanus occidentalis	Western yellow-billed cuckoo	F: SpC CA: E	xB, R	In serious decline throughout CA. Small breeding population along lower Colorado River, but apparently does not breed in Salton Trough. Suitable dense riparian (willows, cottonwoods) habitat exits, especially in upper Whitewater River.
Strigiformes				
Micrathene whitneyi	Elf owl	F: SpC CA: E		Present spring and summer. Breeds along lower Colorado River, Corn Spring, and (formerly) Cottonwood Spring at the south end of Joshua Tree National Monument. No evidence for breeding in Salton Trough. Decline from habitat destruction and competition for nest cavities from introduced European starling (*Sternus vulgaris*).
Athene cunicularius hypogea	Burrowing owl	F: SpC CA: SpC	B	70–80% of CA breeders are in Imperial Valley; ~6500 breeding pairs, ~70% of entire CA population. Feeds on insects and small vertebrates in fields. Nests in former ground squirrel burrows, especially on near-vertical walls of canals and drains. Decline because of rodent control.
Asio otus	Long-eared owl	F: – CA: SpC	B	Winters in small numbers, but can be found any time of year in riparian woodlands and *Tamarix aphylla* groves. Very localized. Only local breeding site is at Yaqui Well in Anza-Borrego State Park. Feeds on small rodents.
Asio flammeus	Short-eared owl	F: SpC CA: SpC		A few winter. Feeds on insects and small mammals. Often active during the day.
Apodiformes				
Chaetura vauxi	Vaux's swift	F: SpC CA: –		Sometimes very common at northern Salton Sea during migration. Aerial insectivore.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Piciformes				
Melanerpes uropygidialis	Gila woodpecker	F: SpC CA: E	B, R	Resident near Brawley, nesting in date palms; wanders to Coachella Valley. Formerly common throughout Salton Trough. Feeds on insects in trees, berries, and cactus fruits. Decline from habitat destruction and competition for nest cavities from introduced European starling.
Colaptes chrysoides	Gilded flicker	F: – CA: E	B	Resident in small numbers. Feeds on insects in trees and on the ground. Decline from habitat destruction and competition for nest cavities from introduced European starling.
Passeriformes				
Tyrannidae				
Contopus cooperi	Olive-sided flycatcher	F: SpC CA: –		Rare spring and fall migrant; a few spend the summer, but do not breed. Does not winter. Perches on exposed limbs and hawks flying insects.
Empidonax traillii eximus	Southwestern willow flycatcher	F: E CA: E	xB	Uncommon fall migrant in dense riparian woodlands and domestic shrubs and trees. Breeding seriously impacted by brown-headed cowbird (*Molothrus ater*) nest parasitism and habitat destruction. Insectivore. A second subspecies, *E. traillii brewsteri*, is common during migration and is not endangered; the two subspecies are nearly impossible to distinguish.
Pyrocephalus rubinus	Vermilion flycatcher	F: – CA: SpC	xB, B+	Spring migrant. Formerly bred, but now very rare: the only regular desert breeding is at Morongo Oasis. Bred near Holtville in 1978. Requires riparian woodland or thickets near open water, alfalfa fields, etc.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Myriarchus tyrannulus	Brown-crested flycatcher	F: – CA: SpC	xB, B+	Spring and summer visitor. Only regular present breeding site is Morongo Oasis, but may occasionally breed near Mecca. Loses in competition with introduced European starlings for nest cavities.
Hirudinidae				
Progne subis	Purple martin	F: – CA: SpC	B	Resident in very small numbers; nests in hollows in trees.
Riparia riparia	Bank swallow	F: – CA: T	xB, R, C	Present spring through fall; formerly bred, but all breeding colonies probably extirpated in southern CA.
Musicapidae				
Polioptila melanura	Black-tailed gnatcatcher	F: – CA: SpC	B	Scarce resident throughout Salton Trough. Insectivore in dense low native scrub, especially in washes.
Mimidae				
Toxostoma bendirei	Bendire thrasher	F: SpC CA: SpC		Rare summer visitor. Currently breeds only north and east of Coachella Valley.
Toxostoma crissale	Crissal thrasher	F: – CA: SpC	B	Rare resident. Insectivore in dense riparian woodlands and adjacent desert scrub, especially mesquite. Very secretive. Serious decline due to habitat destruction.
Toxostoma lecontei	LeConte's thrasher	F: – CA: SpC	xB	Uncommon insectivore in sparse desert scrub such as creosote and cholla and open farmland. Formerly bred. Serious decline due to habitat destruction.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Laniidae				
Lanius ludovicianus	Loggerhead shrike, butcherbird	F: SpC CA: SpC	B	Resident throughout Salton Trough, in open and semi-open habitats. Feeds on small vertebrates and insects in fields, impales prey on thorns and barbed wire.
Vireonidae				
Vireo belli arizonae	Arizona Bell's vireo	F: SpC CA: E	xB, R	Formerly bred in Salton Trough, and still does along Colorado River. Probably extinct in Salton Trough, due in part to habitat destruction but primarily from nest parasitism by cowbirds. Insectivore in riparian brush, especially willows and mesquite.
Vireo belli pusillus	Least Bell's vireo	F: E CA: E	B, R	Present from spring through fall; does not winter. Insectivore in riparian brush, especially willows and mesquite. Breeds in San Sebastian Marsh, Sentenac Canyon, and Coyote Creek in Anza-Borrego Desert State Park. Decline due in part to habitat destruction but primarily from nest parasitism by cowbirds.
Vireo vicinior	Gray vireo	F: – CA: SpC		Present spring and summer.
Emberizidae				
Parulinae				
Dendroica petechia brewsteri	California yellow warbler	F: – CA: SpC		Spring and fall migrant, rarely winters. Insectivore in riparian and domestic shrubs and trees. Declining due to cowbird nest parasitism.
Dendroica petechia sonorana	Sonoran yellow warbler	F: – CA: SpC		Spring and fall migrant, rarely winters. Insectivore in riparian and domestic shrubs and trees. Decline due to cowbird nest parasitism and habitat loss. *D. petechia sonorana* has ben extirpated from Imperial and lower Colorado River valleys.

Table X. Continued.

Scientific name	Common name	Status*	Breeding status**	Notes
Icteria virens	Yellow-breasted chat	F: – CA: SpC	B, R	Rare summer resident and spring and fall migrant; breeds in small numbers. Decline due to cowbird nest parasitism and habitat loss.
Thraupinae				
Piranga rubra	Summer tanager	F: – CA: SpC		Spring and summer. Nearest (small) breeding populations at Morongo Oasis, San Felipe Creek, upper Whitewater Canyon. Decline due to habitat destruction.
Emberizinae				
Amphispiza bellii bellii	Bell's sage sparrow	F: SpC CA: SpC		Rare fall and winter visitant. Granivore in desert scrub and alkali desert scrub.
Passerculus sandwichensis rostratus	Large-billed savannah sparrow	F: – CA: SpC	B+	Rare fall and winter visitant, particularly in *Tamarix* scrub near water and emergent salt marshes; occasional at other times of year. Still breeds in Colorado delta in México, on Isla Montague. Other subspecies much more common. Granivore in desert scrub and salt cedar.
Icterinae				
Agelaius tricolor	Tricolored blackbird	F: SpC CA: SpC	B, R, C	Resident; breeds in dense colonies in cattail, tule, and sedge marshes. Insectivore.

* F: on federal list; CA: on California list; E: endangered; T: threatened; – not listed; SpC: Species of Concern (California Department of Fish and Game) or Migratory Nongame Bird of Management Concern (US Fish and Wildlife Service); these species are of concern because of reduced range, declining populations, nest parasitism from cowbirds, competition for tree cavity nest sites from starlings, or combinations of any of these.

** Breeding status: B: breeds in Salton Trough; B+: breeds sporadically, but not a regular breeder; xB: formerly bred in Salton Trough; S: breeds at Salton Sea; R: breeds in riparian areas; C: colonial nesting species.

Major references used for Table X include: Grinnell and Miller 1944: Cogswell 1977; Garrett and Dunn 1981; Imperial Irrigation District 1994; Small 1994; Thelander et al. 1994; England and Laudenslayer 1995; US Fish and Wildlife Service 1997a; National Geographic Society 1999; Salton Sea Authority and US Bureau of Reclamation 2000a.

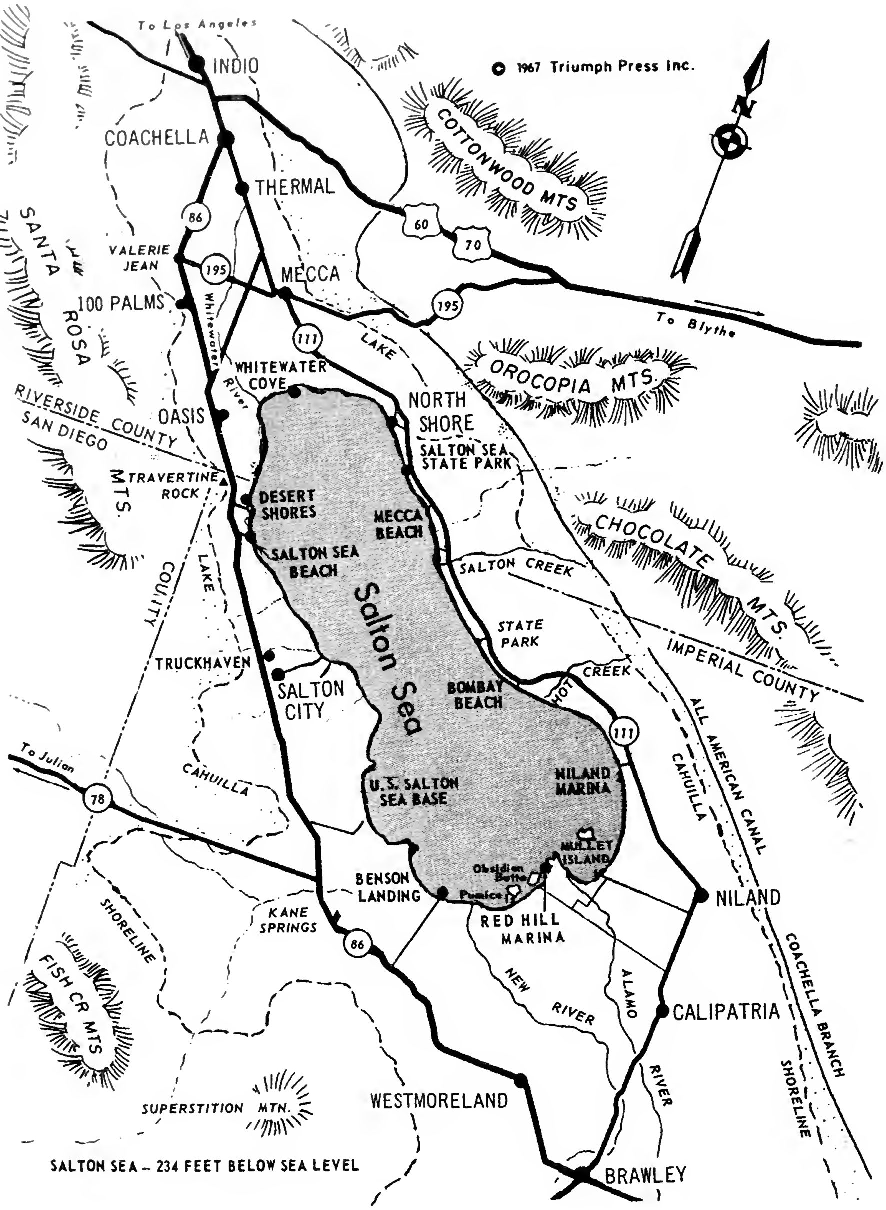

Fig. 1. Political map of the northern Salton Trough, including the southern Coachella Valley, Salton Sea, and northern Imperial Valley, ~1966. The still-stand shoreline of Lake Cahuilla is indicated by a dashed line. The names of several of the volcanic buttes are not current, suggesting that this map was created well before the mid-1960s. Adjacent mountain ranges are depicted schematically. Reprinted from de Stanley, Mildred 1967. The Salton Sea Yesterday and Today. Triumph Press, Los Angeles.

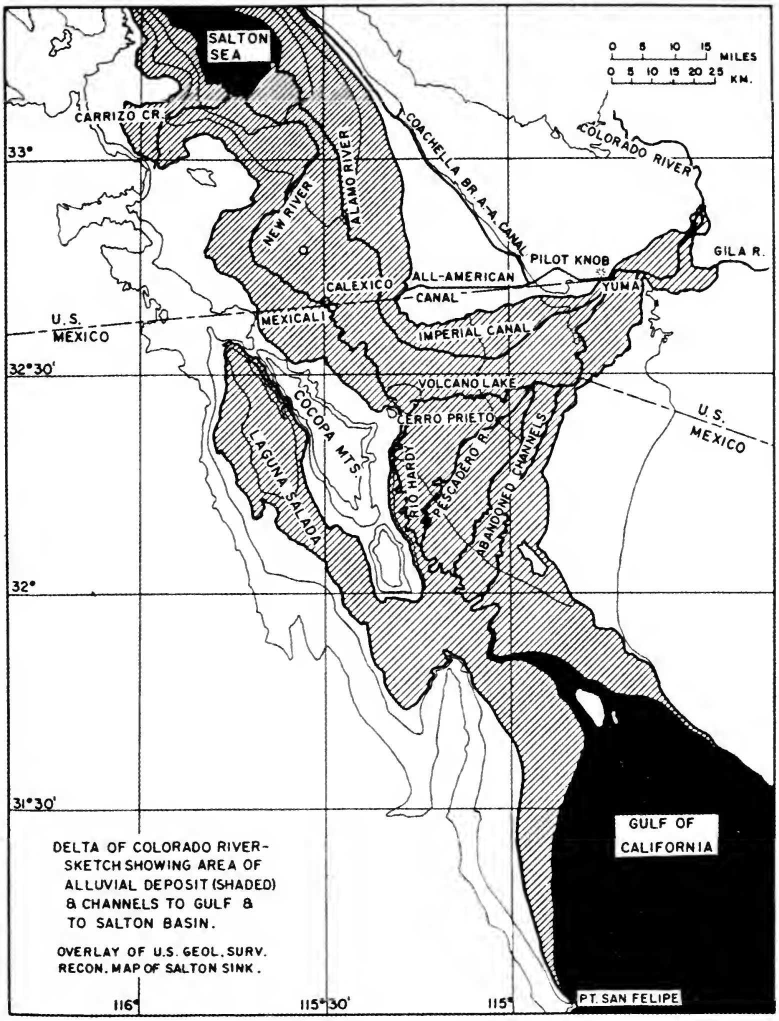

Fig. 2. Map of the southern Salton Trough, showing extent of Colorado River deltaic sedimentary deposits (diagonal lines), based on a US Geological Survey map of 1908. The lowest elevation of the delta dam is at Laguna Volcánica (Volcano Lake), ~10 m above Gulf sea level. Río Hardy is the major distributary when the river overflows Laguna Volcánica, and of Lake Cahuilla when the river fills the Salton Trough. Río Pescadero is the major distributary of the Colorado River when there is any water flowing south of the US/Mexican border. "Carrizo Creek" is correctly San Felipe Creek. "Coachella Br. A-A Canal" is the Coachella branch of the All-American Canal. Reprinted from Carpelan, Lars H. 1961. History of the Salton Sea, in The Ecology of the Salton Sea, California, in Relation to the Sportfishery, Fish Bulletin No. 113, State of California Department of Fish and Game.

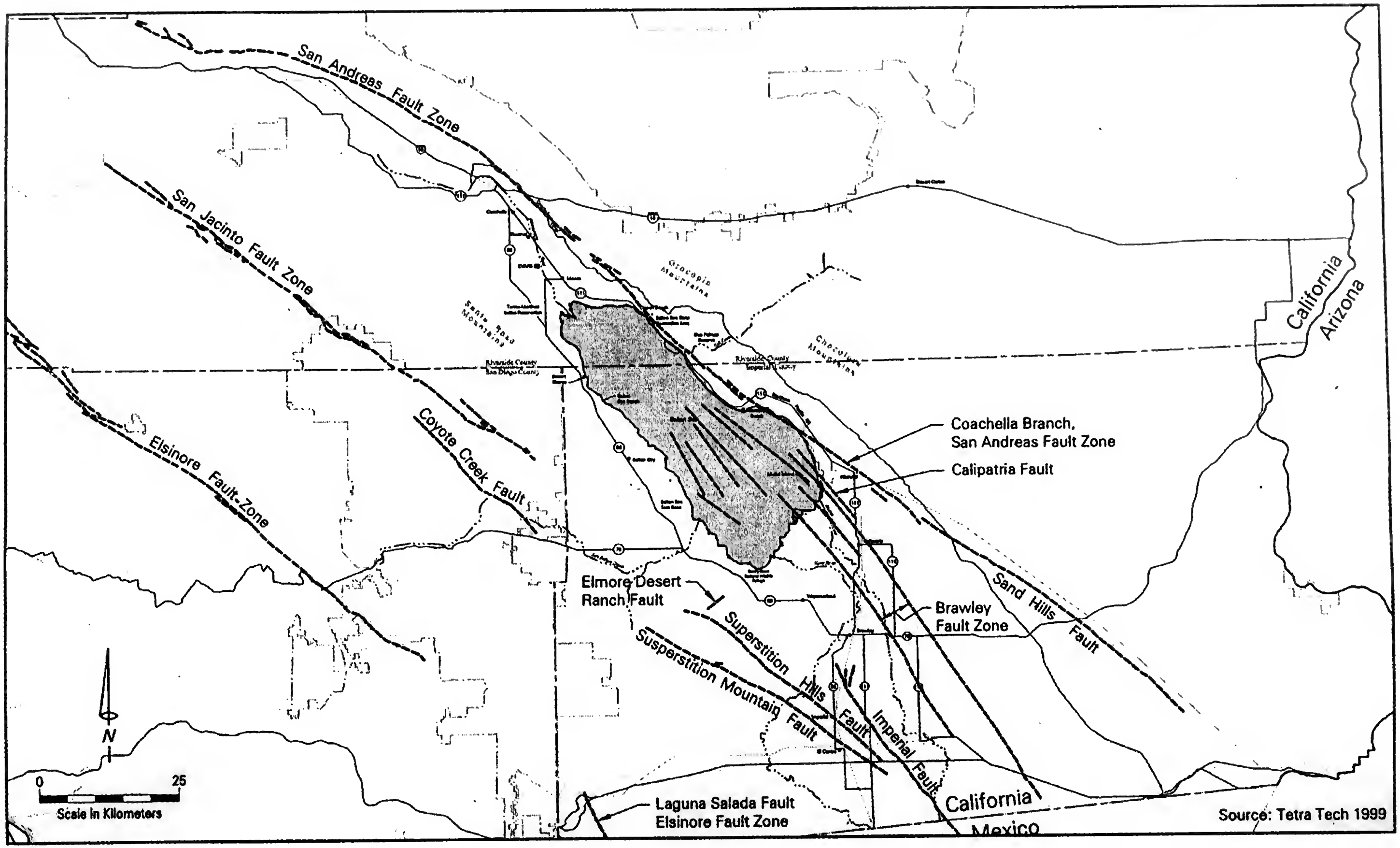

Fig. 3. Fault map of the Salton Trough in California. Known and presumed active fault traces are indicated by dashed lines. Reprinted from Salton Sea Authority and US Bureau of Reclamation. 2000a. Figure 3.3-1, Draft Salton Sea Restoration Project Environmental Impact Statement/Environmental Impact Report.

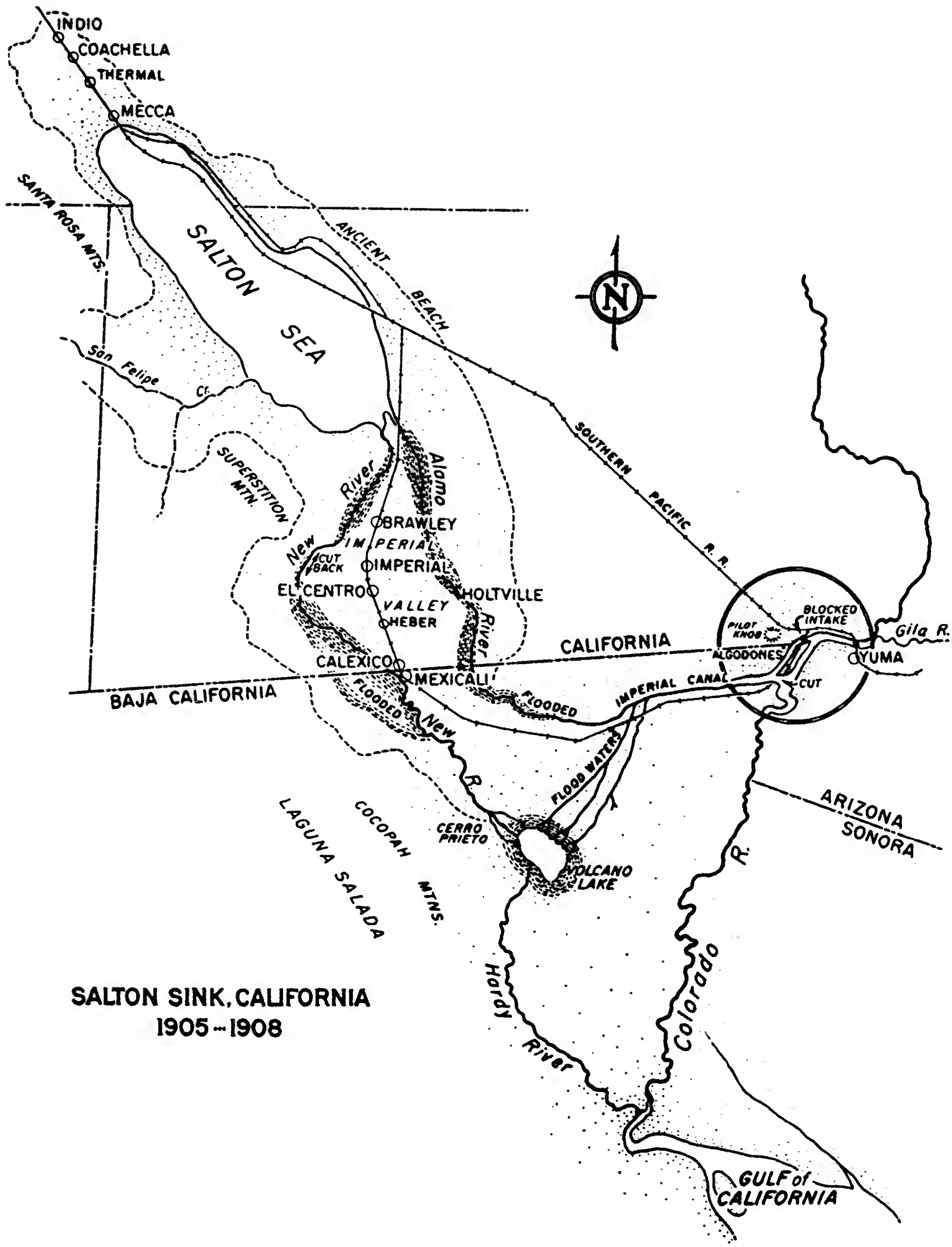

Fig. 4. Map of the southern Salton Trough, showing the new Salton Sea at its largest extent in 1907 (elevation −59 m), distribution Colorado River flood waters from 1905 through 1907 (shaded areas along New and Alamo Rivers and Volcano Lake), and a simplified sketch of irrigation intake structures near Yuma, AZ. The still-stand shoreline of Lake Cahuilla is indicated by a dashed line. The orginal routes of the Southern Pacific railroad tracks are indicated along with the route the transcontinental tracks were relocated to following flooding. Reprinted from Burns, Helen 1963. Salton Sea Story. 7th edition revised. Riverside County Publishing Company, Riverside, California.

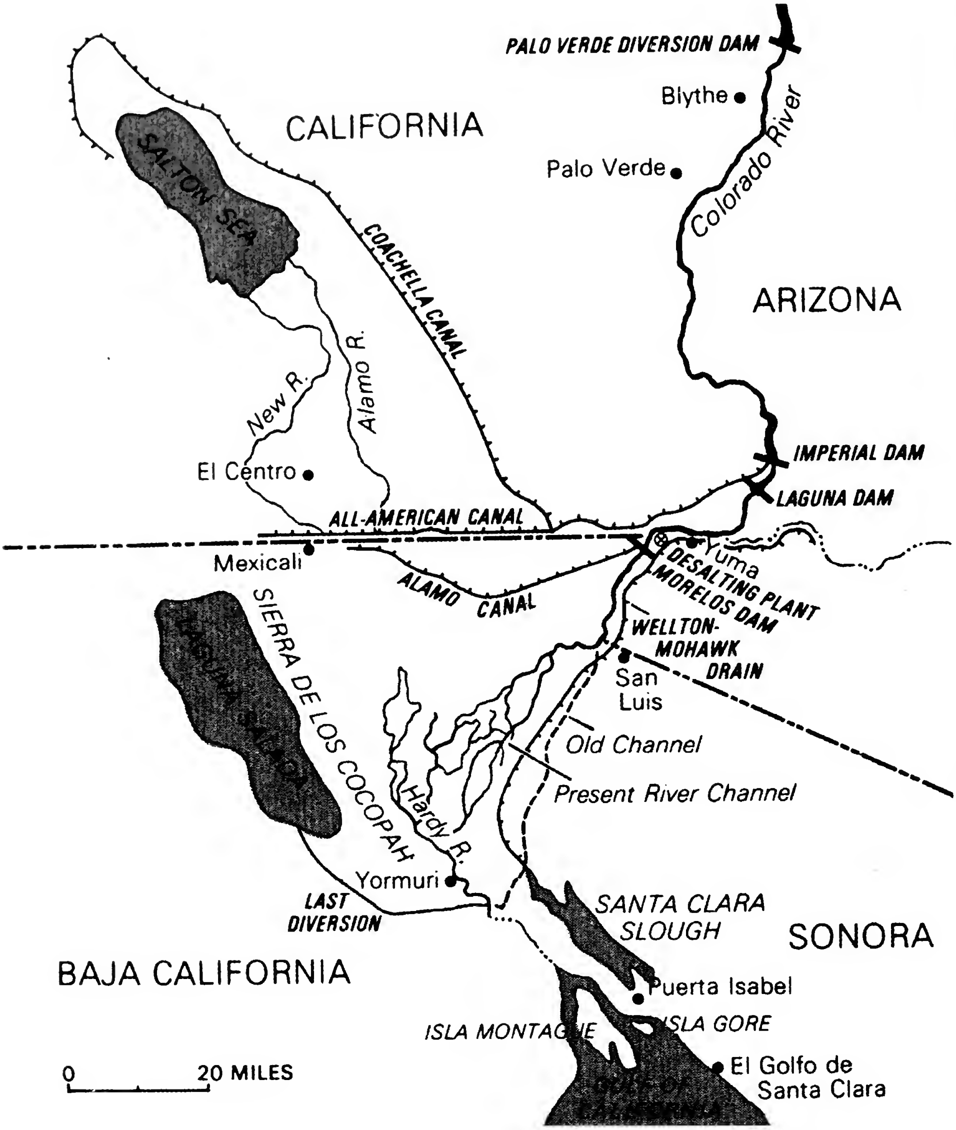

Fig. 5. Map of the southern Salton Trough, showing the Salton Sea, the Imperial and Mexicali Valleys, all dams on the lower Colorado River, the major irrigation canals, the Wellton-Mohawk Drain, and the distributaries of the Colorado River in its delta. Río Hardy heads at the unlabeled Laguna Volcánica. The "present river channel" is Río Pescadero. Note that Laguna Salada receives agricultural wastewater from México. Reprinted from Fradkin, Philip L. 1981. A River No More: The Colorado River and the West. Alfred A. Knopf, New York City.